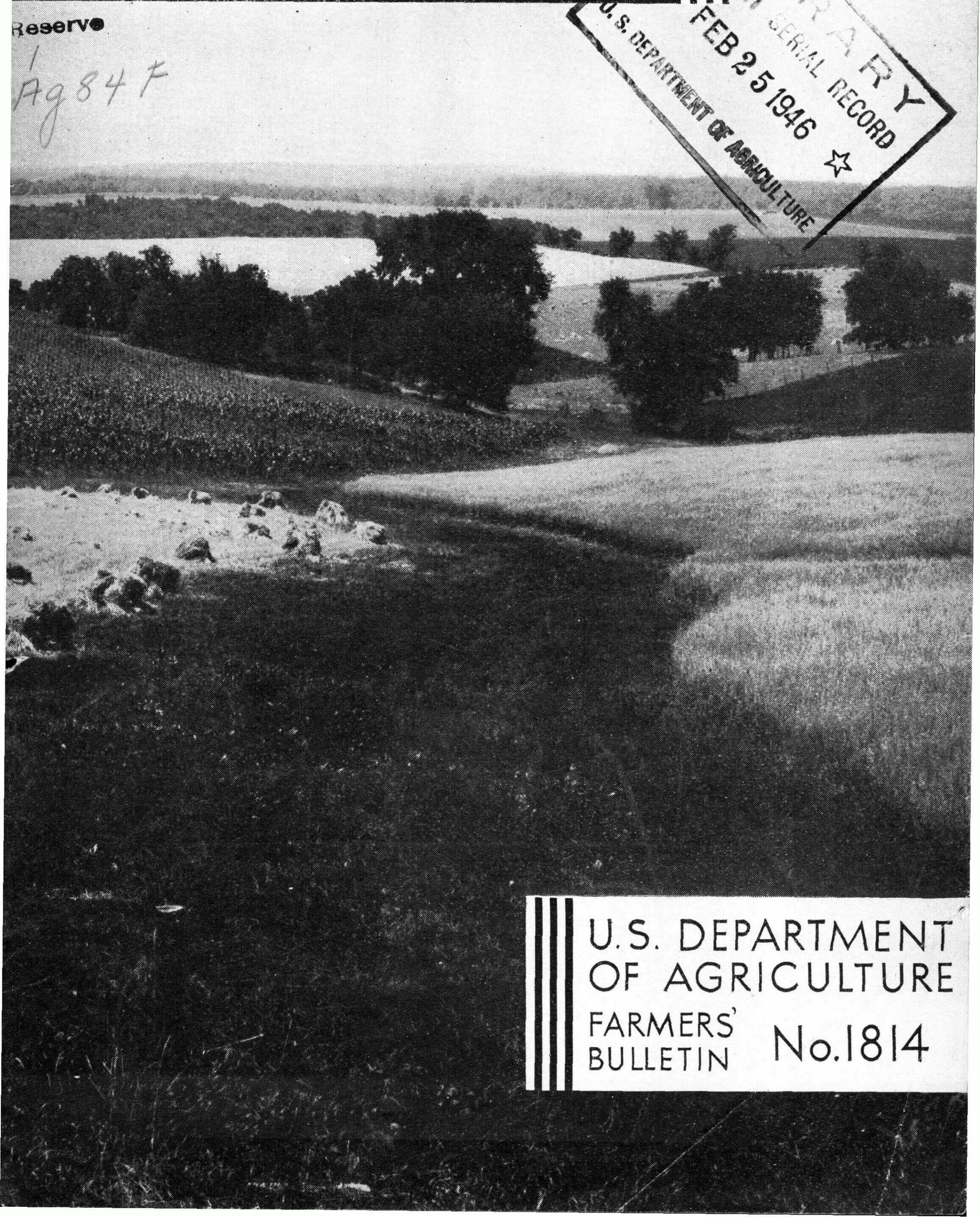
TERRACE OUTLETS AND FARM DRAINAGEWAYS



U.S. DEPARTMENT OF AGRICULTURE
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WHEN PIONEER American farmers cleared forest lands or plowed native sod in order to secure land for the production of farm crops they removed nature's protective covering from many of the natural depressions that collected the run-off from their fields and conveyed it to streams and rivers. Destructive gullying of farm land began in these unprotected drainageways. Conservation farming necessitates the repair or rebuilding of these damaged drainageways and the construction of new outlets to dispose safely of the run-off discharged from terraces, diversion ditches, and other erosion-control measures that are now used extensively.

This bulletin is a compilation of the best information now available for farmers on the construction and use of terrace outlets and the protection, improvement, and maintenance of other sloping drainageways. The term "drainageways" as used in this bulletin refers primarily to channels of surface drainage in the upper reaches of watersheds or in unit drainage basins. "Outlet" is a more restricted term and refers only to drainageways that are provided to receive and convey the discharge from the ends of terraces.

The scope of this material is limited to surface run-off-disposal measures required in upland or rolling terrain where slopes are steep enough to cause channel erosion. It does not cover surface drainage or underdrainage of flatlands where natural drainage is inadequate.

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TERRACE OUTLETS AND FARM DRAINAGEWAYS

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DRAINAGEWAYS AND OUTLETS IN CONSERVATION FARMING

AN INTRICATE SYSTEM of well-protected natural drainageways and watercourses once covered the United States. This branching system of drainageways in the upper reaches of watersheds and flat-channeled watercourses in the lower portions collected and conveyed the surface run-off. These flat-channeled watercourses, the rivers with their branching tributaries, streams, and creeks, formed the central part of this natural run-off-disposal system. Their channels were reduced to flat, nonerosive grades and were practically stabilized. These main watercourses were fed by numerous well-sodded or wooded drainageways that branched out through all natural depressions in the upper reaches of watersheds and collected and conveyed the run-off from each drainage unit. Adequate surface drainage was provided for all drainage units, except possibly those in swampy or low-lying lands. The channels of these drainageways were steep, in comparison with the channels of the main watercourses, but the dense cover of vegetation gave sufficient protection to prevent harmful scouring and the formation of gullies.

But when the forest lands were cleared and the native sod plowed, the protective covering was destroyed in the natural depressions or drainageways as well as on the sloping fields, and little thought was given to the change this was making in the drainage system of farms and the effect it would have on the land (fig. 1). Not only did severe sheet erosion develop on the sloping lands, but the depressions that

[1] This bulletin has been prepared under the general supervision of T. B. Chambers, chief of the Division of Engineering. The parts of the bulletin that relate to the use of vegetation have been prepared in cooperation with C. R. Enlow, formerly chief of the Division of Agronomy. Howard Matson, regional engineer, Soil Conservation Service, and Hans G. Jepson, Division of Engineering, both made valuable contributions.

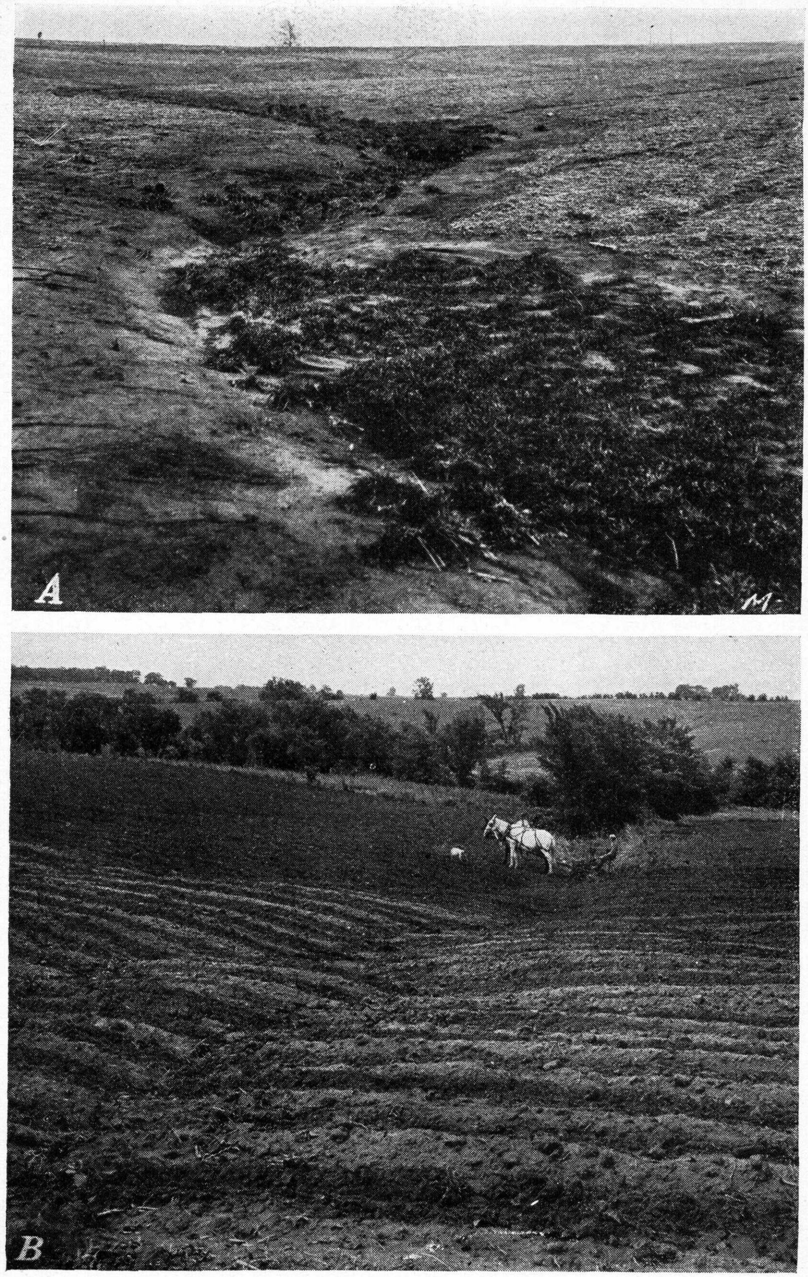

FIGURE 1.—*A*, Faulty tillage practices can be charged with the rapid loss of topsoil from this fertile field. *B*, This natural depression is still a drainageway, even though it has been stripped of its protective plant cover. Without that cover the drainageway will become a starting point for gullies.

had been left unprotected were unable to carry the concentrated run-off to stabilized streams or creeks without destructive gullying. Many huge gullies and ditches were started in these natural depressions and gradually branched out into all parts of a farm. They marred the landscape and eventually dissected many fields so completely that economical tillage operations were made exceedingly difficult and many ground-water levels were materially lowered. A large amount of fertile soil was carried away. As the gullying and sheet erosion progressed, many of the fields had to be abandoned entirely (fig. 2). The extensive construction of roads has also greatly changed and complicated the pattern of natural drainage and induced widespread erosion.

Terracing to divert run-off from cultivated fields has been used widely in the South for many years, and the use of terraces is rapidly spreading to other parts of the country. The manner of terrace lay-out and construction and the lack of adequate outlet protection frequently rendered the earlier work ineffective. Considerable care and experimentation were often devoted to the construction of the terraces themselves, but usually little thought was given to the final disposal of the run-off. The terraces caused increased concentration of run-off, which usually aggravated gully erosion in the drainageways and hastened the formation of objectionable ditches. As the drainageways gullied, excessive overfalls advanced up the terrace channels, increasing grades and channel depths until the terraces became a detriment to rather than a means of conserving the soil. Probably more failures of terrace systems are due to improperly planned and protected outlets than to any other single cause.

During the last few years the national conservation movement has led not only to the general recognition of the need for numerous soil and water conservation practices but to an effective coordination of these practices and their application on more farms than ever before. One or more such measures as crop rotations, vegetal covers, strip cropping, contour tillage, diversion ditches, and terracing will eventually become a definite part of conservation practices on a large part of our agricultural lands, even though their use will frequently necessitate a radical change in traditional tillage practices. These measures will give adequate protection only if proper methods of protecting outlets and drainageways are developed to supplement them. Soil conservation measures can give only temporary or partial protection if the drainageways are neglected and allowed to erode. Terracing, in particular, will never be satisfactory unless the terraces empty into properly constructed outlets. In order to provide for the safe disposal of surface run-off, stabilized drainageways will be necessary even in areas where terracing is not used. In fact, the establishment of satisfactory drainageways is one of the initial problems in developing soil conservation plans in all areas where there is surface run-off.

Under the Soil Conservation Act of 1935 the Government has established numerous demonstrational and experimental projects in different problem areas of the United States. These projects have provided opportunity for intensive study in establishing practical

water-disposal systems on cultivated land and have been an impetus to such study. They have provided an opportunity for extensive field obesrvations and trials and for men with special training in engineering, soils, and agronomy to work together on the same problem. From the extensive field operations of these specialists has come a material advancement in the technique of constructing satisfactory outlets and drainageways. During the earlier part of this work, more information was obtained on the design and construction of

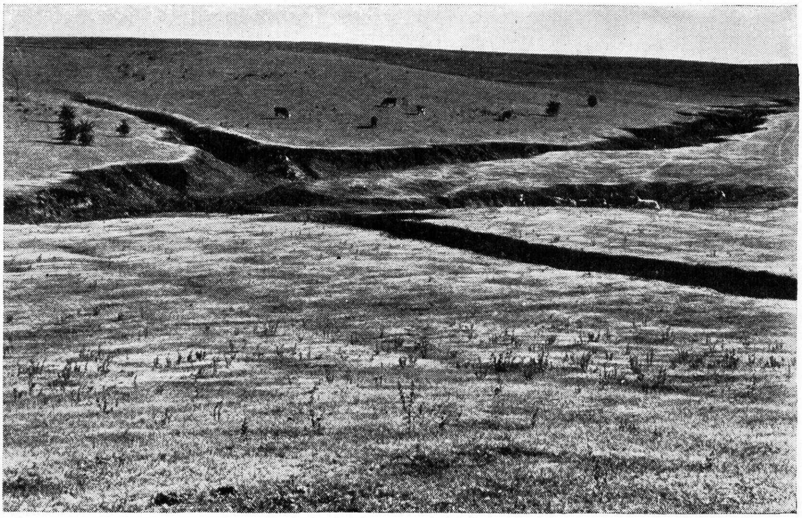

FIGURE 2.—Severe gullying eventually branches out from drainageways that are inadequately protected. This field can no longer be economically tilled.

mechanically protected outlets than on the use of vegetation in run-off disposal. Although mechanically protected outlets were effective and many of them justifiable, the need for a more simple, cheaper, and more practical means of controlling erosion in outlets and drainageways was soon recognized. Recent observations indicate that sod can be used extensively as a protective covering or lining for constructed channels and drainageways in the majority of agricultural areas. When properly used, its resistance to erosion from concentrated flowing waters is much greater than was at first believed.

TYPES OF DRAINAGEWAYS AND OUTLETS

The classification of drainageways and outlets used in this bulletin is shown in table 1. Natural and constructed drainageways are used on both terraced and unterraced areas. On terraced areas there are two main types of outlets, individual outlets and collective outlets. Terraces have individual outlets if the run-off from each terrace is independently discharged over a slope. A collective outlet is a draw or channel that receives the discharge from two or more terraces. A collective outlet is referred to as an outlet strip or a terrace-outlet channel.

TABLE 1.—*Types of drainageways and outlets*

Drainageways	Natural		Constructed		
	With plant cover	Without plant cover	Vegetated	Mechanical	Miscellaneous
Draws (unterraced areas).	Grassed [1]	Rock	Meadow strip	Drop check	Combination.
	Wooded		Pasture strip	Lined [2]	Unlined.
Individual outlets.	Grassed slope [1]	Rock slope	Grassed slope [1]	Drop check	Absorptive.
	Wooded slope		Wooded slope	Lined [2]	Accumulative.
Collective outlets	Grassed [1]	Rock	Meadow or pasture strip.	Drop check	Combination.
	Wooded		Field or roadside channel.	Lined [2]	Unlined.

[1] Often referred to as "meadow" or "pasture," depending on how the forage is utilized.
[2] Discharge velocities are usually higher in lined outlets, and the channels are sometimes referred to as high-velocity channels.

NATURAL

A few farmers were farsighted enough when they first plowed new fields to leave the original plant cover undisturbed in natural depressions, the carriers of run-off from their fields (fig. 3). These farmers have invariably been well repaid because the original cover of vegetation has prevented gullying and made unnecessary costly expenditures to reestablish a protective covering. These few undisturbed draws are now the only drainageways still protected by their original vegetal cover. They should be protected and utilized to the fullest extent possible because it is usually difficult to reestablish or duplicate the native vegetation, and, at best, it is likely to be a costly procedure.

Natural drainageways may also include some rocky slopes or draws that convey run-off and are adequately protected from erosion by rock or gravel deposits. These are often referred to as rock washes.

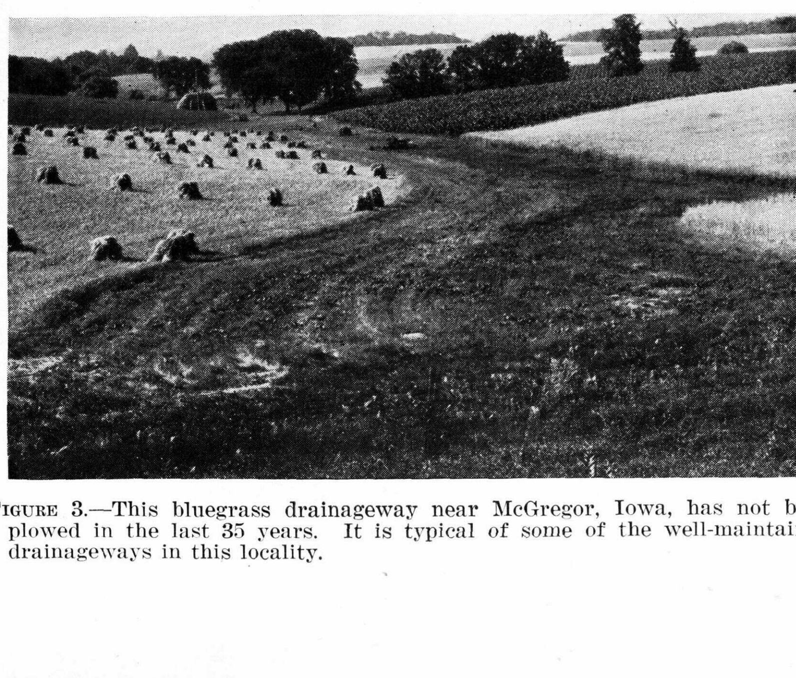

FIGURE 3.—This bluegrass drainageway near McGregor, Iowa, has not been plowed in the last 35 years. It is typical of some of the well-maintained drainageways in this locality.

Natural drainageways that have been only partially damaged by overgrazing or the development of small gullies or breaks in the original cover can usually be repaired and restored. The sooner this is done the more successful it will be and the smaller will be the expenditure of labor and materials required. Frequently the plant cover can be revived by only restricting grazing on the area for one or more seasons. In addition to protection from overgrazing, the more severely damaged areas may require fertilization and the reestablishment of vegetation on certain portions by seeding or sodding. It is usually much easier to repair a few weak patches or damaged spots in a drainageway in which the major portion is still covered with the natural vegetation than to establish a new vegetal cover over the entire area. Once a complete cover has been restored, it should be protected from future damage. Well-protected natural drainageways usually prove to be the most satisfactory.

CONSTRUCTED

Since so many of the natural drainageways have been severely damaged by gullying or have had their protective covering completely destroyed, it is necessary either to construct new ones or to rebuild old ones in order to provide adequate means for the safe disposal of rainfall that cannot be economically utilized on the watershed. The reconstruction of these drainageways is usually most satisfactory if the natural features of the drainageway are reproduced as nearly as possible. There are some areas, however, where the soil and climate or the artificial conditions introduced with agricultural practices may justify or even necessitate some modification of nature's procedure. Constructed drainageways and outlets now in use can be classified in the three groups indicated in table 1: (1) Vegetated, (2) mechanical, and (3) miscellaneous.

Vegetated drainageways and outlets are those in which some form of vegetation, usually some dense-growing grass, is established to protect the soil from erosion. Several types have been developed in order to provide for the variations in local conditions and topography. If a natural swale or depression is retired to permanent vegetation for the purpose of conveying run-off from either a terraced or unterraced area, it is referred to as a meadow or pasture strip, according to the use made of the forage (fig. 4). If used for hay production, it is a meadow strip; if it is to be grazed, it is a pasture strip. Slopes may be vegetated and used for individual terrace outlets. Restricted vegetated channels are frequently used as collective terrace outlets. They differ from grassed strips in that the formed or restricted channel concentrates the run-off on a narrower area (fig. 5). They may be located either in fields (field channels) or along the highway right-of-way (roadside channels), where they usually serve a dual purpose by conveying the run-off from the highway as well as from the adjacent land. Because the cross section of constructed channels is smaller than that of the meadow or pasture strips, the velocity and depth of flow in these channels is greater, and therefore more precaution is necessary in

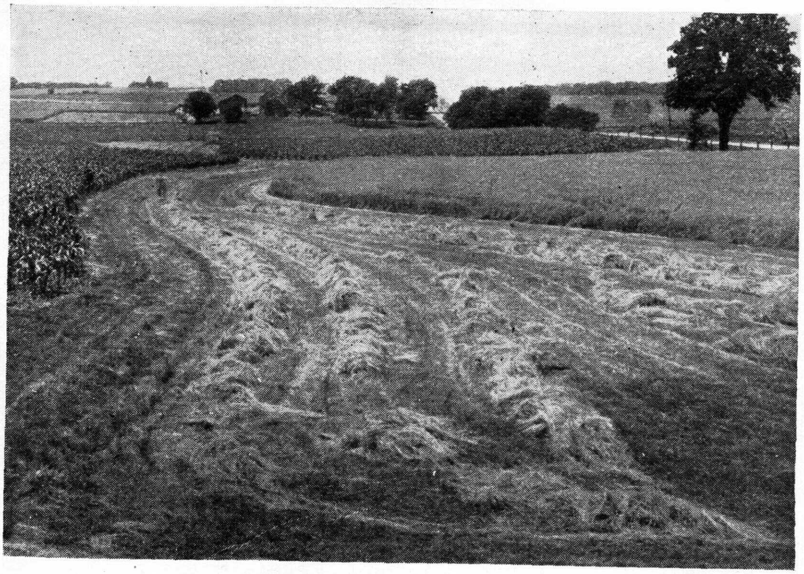

FIGURE 4.—A meadow-strip drainageway that gives satisfactory run-off disposal. The hay crop grown on this drainageway provides an income from the land.

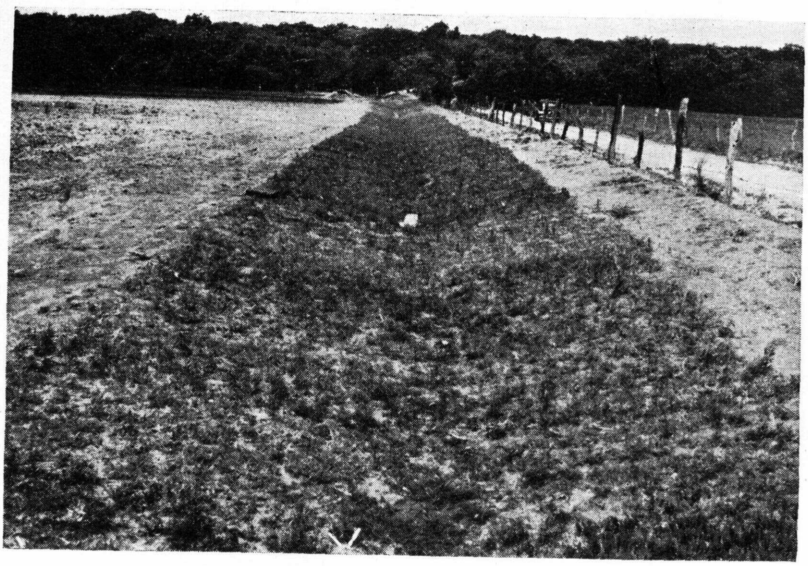

FIGURE 5.—V-shaped vegetated channels such as this are sometimes used where a satisfactory plant cover can be provided, where the run-off is small, and where it is desirable to concentrate the discharge on a restricted area.

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their design and construction. The channel cross sections are limited to those that it is practical to construct, vegetate, and maintain. Where one channel will not provide adequate capacity, multiple channels, which consist of two or more parallel channels, may be used.

Mechanical protection is usually used only in outlets where climate and soil conditions restrict the development of an adequate protection of vegetation. Where unusual conditions prevail, mechanical protection may even be necessary in drainageways on unterraced areas as well as in outlets on terraced areas. Structural protection such as masonry, asphalt, or metal drop checks or linings are used to prevent advancement of overfalls and channel erosion. Low-velocity mechanical outlets are built by using a series of drop-check structures at definite intervals to reduce the channel grade (fig. 6). The

FIGURE 6.—Drop-check structures reduce the grade of this terrace-outlet channel. The run-off is slowed down.

flat grades between structures prevent the run-off water from attaining a scouring velocity. If considerable run-off must be conveyed over steep slopes it is sometimes necessary to provide a continuous channel lining of an erosion-resistant material such as masonry, asphalt, or metal. The steeply sloping conduits require minimum cross-sectional areas, and they produce high channel velocities, but the structural linings prevent harmful scouring (fig. 7). These conduits may be of the open type, placed at the ground surface, or of the

FIGURE 7.—This outlet channel is protected by a continuous lining of rubble masonry.

closed type, which is usually placed under the surface. Considerable precision and care must be exercised in the use, design, and construction of mechanically protected outlets.

Numerous miscellaneous types of drainageways have been used satisfactorily in various sections of the country. Their use, however, is almost entirely dependent upon certain local conditions. Where flat slopes prevail, unlined or unprotected drainageways are often satisfactory. In combination outlet channels more than one type of protective measure is used to provide satisfactory run-off disposal. If the combination consists of vegetation and mechanical structures the vegetation is usually used in the upper reaches of the channel and the mechanical measures in the lower portions. Absorptive outlets are those in which contour furrows, ridges, ditches, or other such means are used to collect and hold the run-off until it is absorbed by the soil. In limestone areas it is sometimes possible to dispose of run-off from terraced fields or other land by directing it into sinkholes, which are common in these areas. Run-off may also be discharged directly into farm ponds, dugouts, or similar reservoirs and stored for recreation or for use by livestock or wildlife.

PLANNING RUN-OFF-DISPOSAL SYSTEMS

The success of conservation measures is dependent upon satisfactory drainageways. In the reorganization of farm plans for the establishment of proper land use and soil conservation measures the planning of these drainageways should usually be considered first.

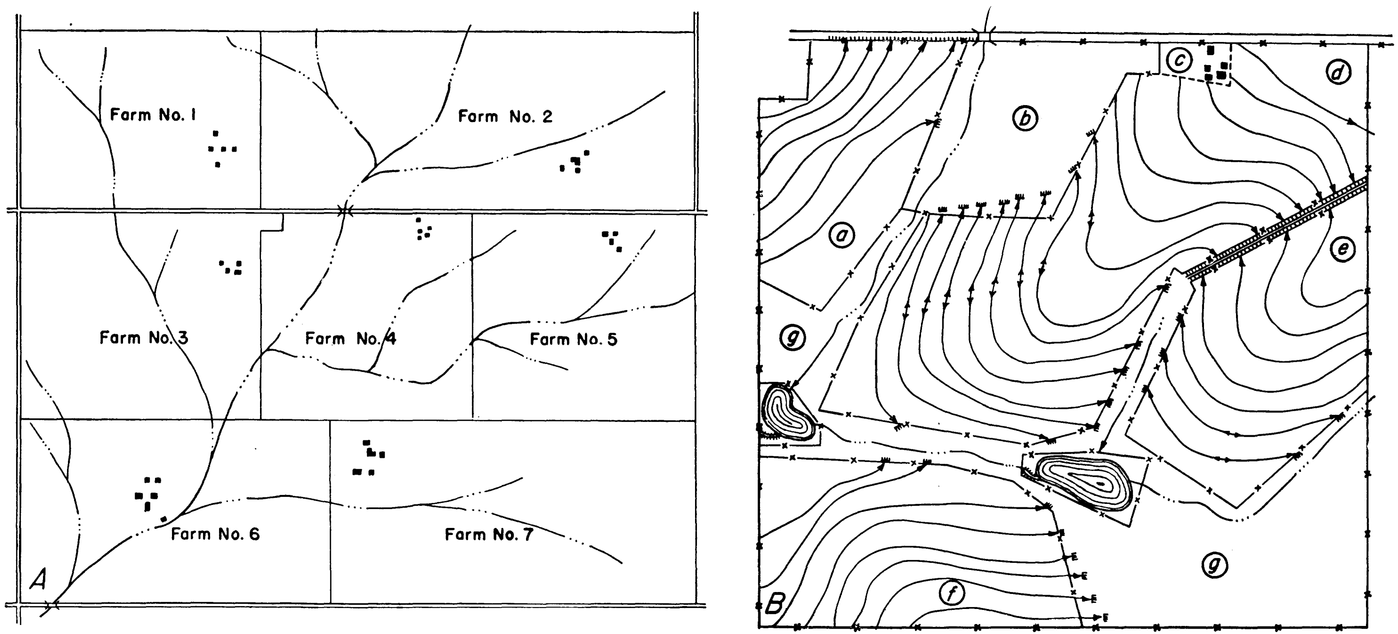

FIGURE 8.—*A*, The natural drainage depressions for this group of adjoining farms illustrate why it is frequently necessary to plan a surface-drainage system for any individual farm in conjunction with that of one or more adjacent farms. *B*, A water-disposal plan for farm No. 4, shown in *A*. The arrows on the terrace lines indicate the direction in which the terraces drain. On fields *a*, *d*, *e*, and *f* crop rotations, contour tillage, terracing, and strip cropping are practiced. Field *b* is in woods, and field *g* is in pasture. The pasture has been extended to include two farm ponds and the drainageways that carry run-off from fields *a*, *b*, *d*, *e*, and *f*. Part of the terraces on field *a* discharge into a roadside outlet channel cooperatively constructed and maintained. The upper part of the drainageway between fields *d* and *e* is a sodded channel and carries run-off from the adjoining farm.

Adjusting field boundary lines, terracing, strip cropping, and other conservation measures are often necessary to assure the most satisfactory drainageways. It would be poor planning to expend money and effort on contour cultivation, conservation rotations, strip cropping, or terraces and to neglect the drainageways. Gullying in drainageways would eventually destroy any benefits derived from the conservation measures on the adjacent slopes. Run-off-disposal systems can seldom be eliminated because considerable surplus rainfall will generally be discharged from all agricultural land, regardless of the soil and water conservation measures used. In semiarid regions, where absorptive measure can be used to retain most of the rainfall, there is less need for drainageways.

The importance of developing on a farm a run-off-disposal plan that is in harmony with drainage plans on adjacent farms or fields is evident when it is realized that run-off discharged from one area usually passes over adjacent areas before it reaches a regular watercourse. Natural depressions generally provide the most satisfactory drainageways. Attempts to establish new ones in other locations to accommodate individual plans or conservation practices frequently lead to serious difficulties. If a complete water-disposal plan is not made at the outset, a series of unrelated outlets and drainageways is frequently developed. They may follow farm roads, field or property lines, or other similar features that have no definite relation to natural drainage courses. Many of these individual drainageways that result from haphazard planning cannot be utilized efficiently when additional conservation measures are established, and they may even hinder the use of subsequent conservation practices.

It is usually necessary to plan surface drainage systems according to drainage units. A drainage unit comprises a natural depression or drainageway, together with the adjacent land that slopes toward it. Since farm boundary lines seldom coincide with natural drainage divides, it is frequently necessary to consider the fields on adjacent farms in developing preliminary drainageway plans for a single farm. Figure 8 shows that natural drainageways may cross several farms in such a way that run-off disposal must be planned for individual farms in accordance with the natural drainage of adjacent farms. With a properly planned procedure, individual drainageways can usually be established so that all the drainageways on a single farm or on adjacent farms can be fitted together without difficulty or expense when the final job is completed for the entire drainage unit.

The first step in planning any type of run-off-disposal system for a field or farm is to make a physical inspection of the adjacent areas as well as the area under consideration and note topographical features such as drains, laterals, ridges, slopes, and gullies and any other features that may influence the location of drainageways. Field and property lines, roads, buildings, and fences should be noted. This preliminary inspection will make possible a tentative selection of at least the main depressions that should be reserved for permanent drainageways. The number of lateral drainageways required will depend not only on the topographical features but also on the soil conservation practices used. Where run-off interception is to be provided by the use of such

means as terraces and diversion ditches the run-off is usually diverted from one or more minor depressions, so that the number of drainageways that must be constructed is materially reduced. As land use and soil conservation plans are developed for the farm, the field boundaries, fence lines, and meadow or pasture areas can often be changed so as to make it easier to establish and maintain the selected drainageways. For example, pasture and meadow areas can often be arranged to include the main drainageways. If this is done, it is easy to utilize the grass on the drainageways and to maintain them. The vegetation in the pasture or meadow can be extended across the drainageways, and the subsequent grazing and mowing will usually take care of the principal part of the maintenance.

UNTERRACED AREAS

On unterraced areas used for the production of farm crops it is usually best to use wide grassed drainageways for carrying the run-off over slopes that are steep enough to produce erosive velocities. Plans should provide for continuous protection of the main depressions from field to field and from farm to farm until a stabilized watercourse is reached. If continuous protection is not provided, overfalls usually develop and undermine parts of drainageways that may otherwise be adequately protected. Sloping lateral depressions that carry a considerable amount of run-off must also be protected. Where a large enough area of land cannot be retained economically for a grassed drainageway, where an adequate plant cover cannot be established, or where large amounts of run-off must be carried, it may be necessary to use partial or even complete structural protection in drainageways. However, this type of protection is usually not necessary and, except for special conditions, cannot be economically justified. On highly developed orchard lands or other high-income crop areas structural protection may be justified.

The difficulty of establishing adequate grass covers and the cost of the land that must be retained for run-off disposal discourage the extensive use of vegetated drainageways.

It is sometimes more difficult to provide practical protection for drainageways on cultivated areas where no run-off-diversion measures are used than on terraced areas. In areas that have rolling relief the upper reaches of watersheds branch out into numerous natural depressions, each of which carries run-off to the main drainageway. Where these depressions are comparatively close together and are adequately protected they may form numerous grassed strips that dissect a field to such an extent as to prevent economical tillage operations (fig. 9). This condition will favor retirement of the entire field to a permanent cover or the use of applicable run-off-diversion measures that eliminate some of the vegetated drainageways and thus facilitate economical tillage practices. A field divided in this way is particularly troublesome where large tillage machinery is used. On land that is to be retired to a permanent plant cover the planning of a satisfactory run-off-disposal system is comparatively simple, because each natural depression can serve as a natural drain-

ageway after the cover is established. Establishing a satisfactory cover will usually prove to be a more difficult problem.

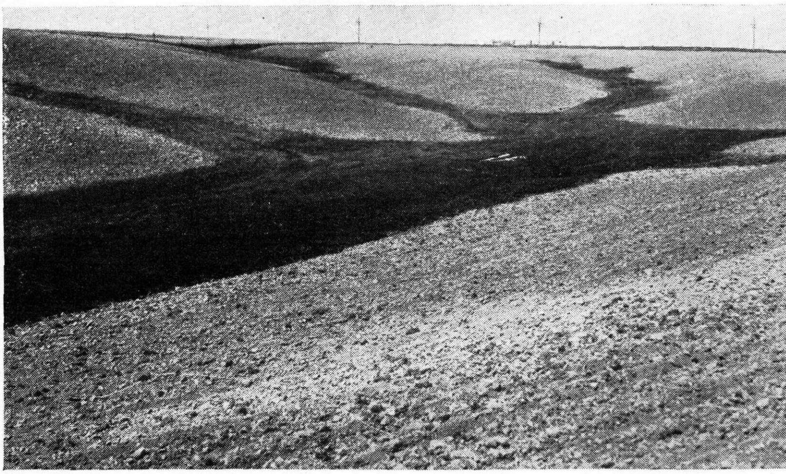

FIGURE 9.—In cultivated fields that have rolling relief such as this it is sometimes dffiicult to provide adequate protection in all natural depressions without seriously interfering with economical tillage operations. Terracing or retirement of the entire area to permanent cover may be advisable.

TERRACED AREAS

The problem of locating and establishing outlets is inseparably associated with planning the terrace system. The cost of terrace construction and the success of the terraces are dependent upon the proper planning of outlets. Adjustments in the location and in the direction of the flow of terraces will often greatly simplify outlet control. A slight variation of the location of the first terrace or a change in the vertical interval on subsequent terraces may make it possible to discharge the run-off from the terrace at a point where outlet protection is comparatively simple. Changing the direction of the terrace grade near the center of a terrace or running the grade of alternate terraces in opposite directions will diminish the concentration of run-off and often make it possible to distribute the run-off from a terraced field over native cover on adjoining areas. Where special outlet strips or channels are required, it is often more satisfactory to drain terraces toward the outlet channels from both sides so that each outlet channel will serve a larger area. Such an arrangement reduces the number of channels needed. As a general rule all collective terrace outlets should be as straight as it is practical to make them, and they should be planned so as to provide continuous protection from the uppermost terrace on the slope down to stabilized watercourses. If run-off is discharged from areas higher on the slope than the terraces it is usually necessary to develop the terrace-outlet system so as to carry this additional run-off.

Terrace outlets should be located where they can be constructed and maintained most economically and where they will function satisfactorily. Preference should be given to the natural depressions or more gentle slopes and to field or property lines, where the outlet channels will give minimum interference with tillage practices. Other topographic features that must be considered in determining the location of outlets are the size of fields, as it affects the drainage area at the outlets, and the grade and stability of natural drainageways below the outlets. Unprotected road ditches and large or crooked gullies should seldom be used to dispose of terrace run-off because it is difficult and expensive to protect and maintain them. Run-off should usually be diverted from such locations. However, properly constructed and protected highway ditches can often be used to advantage for the disposal of run-off from terraces. It has sometimes been found desirable for the landowner and highway officials to make a definite agreement to develop a joint outlet channel that will serve the dual purpose of draining the farm terraces and the adjoining highway (fig. 10). It may often be advantageous for two

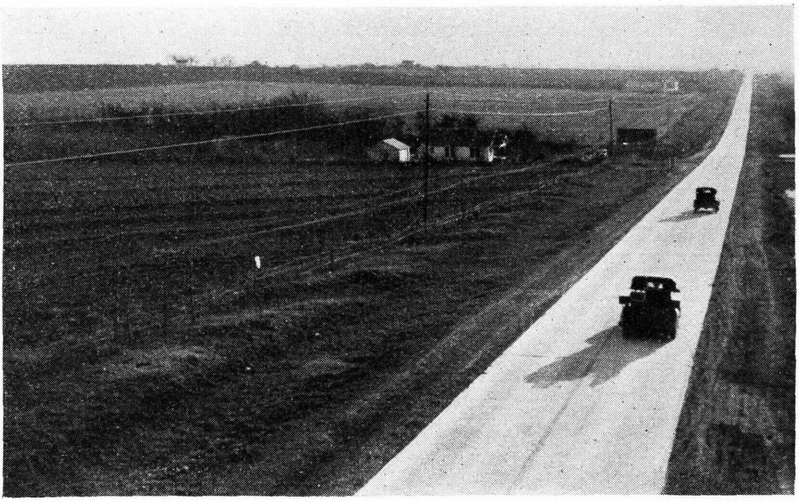

FIGURE 10.—A cooperatively constructed and maintained terrace-outlet channel and highway-drainage ditch. If a satisfactory agreement can be arranged between the landowner and highway officials the same ditch may be used to carry the run-off from both the highway and the adjacent farm land.

or more landowners having terraced fields in the same drainage unit to plan a joint outlet system, provided they can make a satisfactory agreement for joint construction and maintenance of the terraces and outlets. The importance of satisfactory preliminary plans for both terraces and outlets lies in the fact that terraces, when once constructed, are permanent unless they are improperly maintained. Their relocation is costly and difficult. Furthermore, improperly located and improperly protected outlets may cause the cost of outlet construction to exceed the construction costs of the terraces them-

selves, and this makes the final cost so great that it discourages terracing where it is needed for adequate soil conservation.

It must be recognized that the problem of terrace-outlet protection is neither equal in importance nor uniform in character in the various climatic, geographic, soil, and type-of-farming regions. Some varieties of grasses and methods of establishment are well adapted to certain localities but are impractical in others. The local rainfall intensities, the distribution of the rainfall, and the season of the year at which terrace-outlet construction is undertaken will have a marked influence in determining the most satisfactory procedure. Where amounts of run-off are large, or where high land values prevail, certain more expensive types of outlets may be justified. Because of the diversity of conditions it is obviously impossible to select a standard method of outlet control and attempt to apply it universally. A satisfactory procedure is to determine in what order the various types of outlets should be considered and what form of each type is best adapted locally and can be economically established or constructed.

From the standpoints of economy and practicability, including ease of establishment on the average farm, the various types of terrace outlets should be considered in the following order: (1) Grassed or wooded individual outlets; (2) meadow or pasture outlet strips; (3) grassed channels; (4) mechanically protected channels.

In field practice natural conditions often prohibit the use of certain of these types, but they should usually be given consideration in the order named and no method discarded as impractical until thorough investigation has proved it to be so.

The simplest and most ecenomical type of outlet is usually secured if terraces can be discharged directly onto well-established sod or other plant cover that will provide sufficient protection for the additional run-off from the terraces. Good pasture or meadow sods usually give the safest protection. An unburned and ungrazed woodland on relatively flat slopes may sometimes be satisfactorily used if necessary. Considerable precaution must be taken in the selection of the wooded slope and in the manner in which the concentrated run-off is discharged into the woods. Usually steep wooded slopes should not be used. Poorly sodded areas, grazed woods, or fields retired from cultivation to pasture or meadow can often be utilized for individual outlets, provided the necessary measures are applied to rejuvenate or reestablish a good plant cover before it must carry the additional run-off from terraces. Individual outlets (fig. 11) will usually be most applicable in areas of rolling relief where cultivated fields are small to medium in size and where a considerable proportion of the farm land is retained for pasture and meadow.

If a collective-type outlet is necessary, turning natural depressions into meadow- or pasture-strip outlets and drainageways not only provides a practical method of disposing of the run-off but also makes effective use of areas that otherwise would often be unproductive. The meadow or pasture strip is a simple type of outlet that fits in with practices on farms where there is need for pasture or hay; and many such outlets now in use have proved to be the most profitable areas on

the farm. The convenience of using drainageways for hay production, however, should not be used as a justification for not including hay crops in the rotations on adjacent fields when their use is necessary to provide effective conservation. Natural meadow and pasture strips already exist in some areas, and in others where there is a suitable depression this type of outlet can often be developed satisfactorily at a relatively low cost.

Where the slope does not exceed 5 to 6 percent, a wide, shallow depression is preferable, and the terraced fields should be located so

FIGURE 11.—Run-off is here discharging from an individual terrace over a well-sodded slope. The outlet end should be located and shaped so as to spread the discharge in as thin a sheet as possible over the slope.

that the terraces can be discharged directly into the grassed strip. The presence of a few small gullies in the depression does not necessarily prohibit its development into a satisfactory strip outlet because usually the small gullies can be graded or plowed in and the necessary vegetation established.

In localities where good turf can be established but conditions prohibit the conversion of sufficiently large areas to meadow, pasture, or wide grassed drainageways, a more restricted type of channel can be used. These outlet channels, designed to carry the discharge from the terraces at a higher velocity, do not require for a given amount of run-off a cross-sectional area as great as that in the meadow or pasture strip. Their success is dependent upon the establishment of a turf that will withstand comparatively high run-off velocities without harmful scouring. Their cross sections must be propor-

tioned to provide ample capacity, facilitate proper maintenance, and restrict the maximum channel velocity to that which the turf will carry safely. Usually the maximum velocity in channel-type outlets is from three to four times greater than in wide strip-type drainageways, and the width of the area required can frequently be reduced to as much as one-tenth that commonly used for the wider drainageways.

If all types of outlets protected by vegetation are found to be inadequate or impractical, mechanical outlets are usually considered. Their use will ordinarily be restricted to areas where climatic and soil conditions or high land values prevent the development of economical vegetated outlets or where the volume of run-off is so large that vegetated outlets are inadequate. The use of mechanically protected outlets is further limited by economic considerations.

Will the income from the land justify the expense of installation? Are other types impracticable? Before the use of mechanically protected outlets is decided upon, these questions should be answered.

Mechanical protection in outlets will be used most extensively as a supplement to vegetation. Some form of structure is often required at strategic points in grassed outlets, particularly toward the lower ends, where the larger volume of run-off or an abrupt overfall may render protection by vegetation inadequate. In some areas there has been a tendency in the past to underestimate the value of good sod covers, and many overfall structures have been used at points in outlets where a properly designed and constructed sod flume would have served the purpose just as well.

If vegetation and mechanical protection are used in the same channel the vegetation is usually in the upper reaches of the channel and the mechanical protection in the lower portion. It is usually not considered a good plan to use vegetation between or below structures for the purpose of allowing a steeper channel grade. Should the vegetal cover fail, the more expensive structure would also be exposed to failure. If it is necessary to use mechanical protection, only permanent structures of the best design should be used. Inexpensive spreaders and other temporary structures have not generally proved to be of any material benefit in facilitating the establishment of vegetation in outlet channels and have frequently been a detriment.

HYDRAULICS

In the design and construction of all channels for the conveyance of run-off, certain fundamental hydraulic principles must be observed in order to assure satisfactory results. The size of drainage areas and the rates of run-off to be expected should be determined. Dimensions and velocities of drainageways also have to be computed. Drainageways must be made large enough to carry the run-off during heavy storms without overtopping, and they must be constructed so as to avoid undesirable channel velocities. Sufficient field observations and measurements have been made to enable engineers to compute the size and proportions of drainageways with reasonable accuracy, and they have made up tables that materially simplify these computations. These tables are sufficiently accurate for all prac-

tical purposes. If greater accuracy is desired, computations for any particular job can be made by the use of certain engineering formulas and mathematical analysis. For large projects or unusual conditions individual computations are generally desirable, and a competent engineer should ordinarily be consulted.

RUN-OFF

In the computation of required drainageway or channel capacities the maximum rate at which run-off will be discharged from the contributing watershed is more significant than the total amount discharged or the average rate at which it is discharged. Drainageways must have sufficient capacity to convey run-off at the maximum rates that are commonly produced; otherwise excessive overtopping and damage is to be expected during periods of heavy rainfall. The maximum run-off rates for which drainageways are designed usually occur when rains of high intensities fall on saturated or frozen soil and during periods when the fields may be without crops. The maximum run-off rates for which drainageway channels and structures should ordinarily be designed are given in table 2 for different kinds and sizes of watersheds in various sections of the United States. If additional information on rainfall is desired, it can be found in United States Department of Agriculture Miscellaneous Publication 204, Rainfall Intensity-Frequency Data, which gives maximum rates of rainfall that are likely to occur in different localities during periods of 2, 5, 10, 25, and 100 years.

CHANNEL CAPACITIES AND VELOCITIES

Securing adequate capacity and avoiding detrimental scouring and silting velocities are the main hydraulic requirements in the design of drainageways and outlet channels. Controlling velocity is largely a matter of regulating the proportions of channels. Safe maximum channel velocities are dependent upon the erosion-resistant properties of the material used to line the channel. Concrete or metal linings will withstand much higher velocities than sod covers. Since different types of sod covers vary in their ability to resist run-off velocities, the highest velocity for which a drainageway can be designed will depend on the cover to be used. Unlined earth channels offer the least resistance to erosion and can be used only for comparatively low velocities. The velocity in a run-off-disposal channel increases not only as the slope of the channel increases, but as the average water depth (approximately the hydraulic radius) increases and as the surface resistance (coefficient of roughness) decreases. Once the outlet location and type of protection have been selected, it is difficult to change the channel slope or resistance factor, so control of velocity is largely obtained by regulating the average water depth. In wide, shallow channels the velocities are lower than in narrow, deep channels.

Field observations indicate that well-established Bermuda sod outlets can safely withstand velocities of 7 to 8 feet per second for periods of intense run-off ordinarily experienced under normal rainfall con-

TABLE 2.—*Maximum run-off to be expected once in 10 years from drainage areas of 1 to 300 acres*

Watershed characteristics [1]	Group [2]	Run-off from drainage area of—											
		1 acre	2 acres	3 acres	4 acres	5 acres	10 acres	15 acres	20 acres	25 acres	30 acres	35 acres	40 acres
		Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
Rolling timber	1	2	4	5	6	8	16	23	29	35	39	44	49
	2	2	3	4	6	8	15	21	26	32	35	40	45
	3	2	3	4	5	7	13	19	23	28	31	35	39
Hilly timber	1	3	5	6	8	9	18	27	33	40	45	52	57
	2	3	4	6	8	9	17	25	31	36	41	47	52
	3	3	4	5	7	8	15	22	27	32	36	41	45
Rolling pasture	1	5	8	12	15	18	33	47	58	67	77	87	99
	2	4	8	11	14	17	30	43	53	61	70	79	90
	3	4	7	10	13	15	27	38	47	54	61	69	78
Hilly pasture	1	7	13	16	20	24	40	55	67	79	91	102	114
	2	7	12	15	19	22	37	51	61	72	82	93	104
	3	6	11	14	17	20	33	45	54	63	72	81	90
Rolling cultivated	1	8	15	23	29	34	57	77	95	111	128	145	162
	2	8	14	22	27	32	53	71	87	101	116	132	147
	3	7	13	20	25	29	47	63	77	89	102	115	128
Hilly cultivated	1	10	17	27	35	42	70	94	114	134	154	174	196
	2	10	16	25	33	40	64	86	104	124	139	158	177
	3	9	15	23	30	36	57	76	92	107	122	138	154
Terraced rolling cultivated	1	6	9	14	18	21	40	54	68	81	93	107	120
	2	5	9	13	16	20	36	50	62	73	84	97	109
	3	5	8	12	15	18	33	44	55	65	74	85	95

Watershed characteristics [1]	Group [2]	Run-off from drainage area of—										
		45 acres	50 acres	60 acres	70 acres	80 acres	90 acres	100 acres	150 acres	200 acres	250 acres	300 acres
		Cu. ft. per sec.	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*	*Cu. ft. per sec.*
Rolling timber	1	55	62	73	83	90	97	100	145	185	216	245
	2	50	56	65	74	80	86	91	127	160	186	210
	3	43	48	56	63	68	73	77	105	130	150	168
Hilly timber	1	64	71	85	96	104	114	122	165	213	252	285
	2	58	64	75	85	92	102	108	145	184	217	244
	3	50	55	65	73	79	86	91	120	150	175	195
Rolling pasture	1	110	121	143	164	181	197	208	290	369	433	489
	2	99	109	128	146	160	175	185	254	319	371	419
	3	86	94	110	125	137	148	155	210	260	300	335
Hilly pasture	1	128	142	166	190	210	227	241	334	426	497	572
	2	116	128	148	169	186	202	214	294	369	428	490
	3	100	110	128	145	159	171	180	242	300	345	392
Rolling cultivated	1	182	201	238	271	299	324	344	476	605	720	822
	2	164	181	212	242	265	288	306	419	522	620	703
	3	142	156	183	207	226	244	257	345	425	500	562
Hilly cultivated	1	219	241	285	323	358	389	416	580	727	863	986
	2	198	217	254	288	317	345	369	590	630	742	843
	3	171	187	219	246	271	292	310	420	512	600	675
Terraced rolling cultivated	1	137	155	189	223	264	293	315	465	605	720	831
	2	124	139	168	199	234	260	280	409	522	620	712
	3	107	120	145	170	200	220	235	337	425	500	570

[1] "Rolling" and "hilly" correspond to slopes of 5 to 10 percent and 10 to 30 percent, respectively.

[2] Group 1 includes the entire States of Florida and Louisiana, the southern part of Georgia and Alabama, the southern half of Mississippi, and the southeastern part of Texas. Group 2 includes central Texas, all of Oklahoma except the Panhandle section, the eastern half of Kansas, southeastern Nebraska, the southern half of Iowa, western Illinois, all but the southeastern tip of Missouri, Arkansas except for the northeastern corner, South Carolina, those parts of Mississippi, Alabama, and Georgia not covered in group 1 (except for extreme northern parts of these States), the eastern and central part of North Carolina and Virginia, Delaware, the eastern half of Maryland, New Jersey, and the southern extremes of Connecticut and Rhode Island. Group 3 may be used for all other areas, except where local information indicates higher run-off rates

ditions. This velocity has occasionally been exceeded for short periods without harmful results. It is believed that good bluegrass sod will withstand similar velocities, but bluegrass is usually more difficult to establish and maintain than Bermuda sod. Consequently the maximum velocities for which drainageways protected by bluegrass have been designed have usually been only 5 to 6 feet per second. A lower maximum channel velocity is frequently necessary where the climate or soil conditions or seeded meadow grasses produce less resistant covers. For example, recent experimental tests indicate that velocities of 3 to 4 feet per second should not be exceeded in channels protected by lespedeza. Low channel velocities (less than 2 to 3 feet per second) may cause undue silting in vegetated outlets, which will ultimately lead to inadequate channel capacity and overtopping. It is not always possible to eliminate velocities that leave silt in drainageways, but excessive silting can be minimized to a large extent if adequate conservation practices are used on the contributing watershed. Avoiding excessive terrace grades and spacing and properly maintaining outlet channels are particularly effective. If necessary, channel cross sections can often be adjusted, even on comparatively flat slopes, to avoid low or silt-depositing velocities. Using V-shaped channels with little or no bottom width will aid in maintaining desired velocities on flat slopes. An attempt should be made to secure as uniform a velocity as is practical throughout the entire length of an outlet.

The rate at which a channel will convey run-off is determined by multiplying the channel velocity by the water cross-sectional area. This cross-sectional area can be determined by multiplying the average water depth by the width. For example, a channel with an average water depth of 1 foot, a width of 8 feet, and a velocity of 5 feet per second will carry $1 \times 8 \times 5$, or 40, cubic feet per second. Because of the uncertainty concerning the amount and rate of run-off and the difficulty of maintaining exact dimensions under field conditions it is standard practice in determining the size of the channel to be constructed to provide a safety factor by making the channel slightly larger than the computed requirements.

It is much simpler to secure the required discharge velocities and capacities for pasture- and meadow strip drainageways than for channel-type outlets. The minimum practical width of a grassed drainageway that can be used for hay or pasture (seldom less than 75 feet) usually provides ample capacity to carry the run-off from the contributing watershed and to take care of some silting, if silting cannot be entirely prevented. These strip type drainageways on large watersheds should ordinarily have at least 1 to 2 feet of width for each acre of drainage area. Greater widths may be necessary if the curvature across the drainageway is unusually flat. If it is desirable to use grassed outlets of the channel type, the construction dimensions are usually determined by the velocity and capacity requirements. The channel dimensions (depth and bottom width) for assumed channel velocities and side slopes and various slopes and quantities of run-off are given in table 3. If other side slopes are used or if it is necessary to use lower velocities, it will be necessary to make separate computations. For small drainage areas V-shaped

TABLE 3.—*Approximate dimensions of outlet channels with grass covers capable of resisting maximum average channel velocities of 5, 6, or 7 feet per second, with 4 :1 side slopes and with good channel conditions*

Channel slope (percent)	Dimensions	Dimensions required for discharge per second of—																	
		20 cubic feet	30 cubic feet	40 cubic feet	50 cubic feet	60 cubic feet	70 cubic feet	80 cubic feet	90 cubic feet	100 cubic feet	110 cubic feet	120 cubic feet	130cubic feet	140 cubfe iect	160 cubic feet	180 cubic feet	200 cubic feet	220 cubic feet	240 cubic feet
	5 FEET PER SECOND																		
10	Width.....feet..	12	19½	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	4	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
9	Width.....feet..	10½	17½	24	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	4	4	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
8	Width.....feet..	10¼	15½	21½	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	4½	4½	4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
7	Width.....feet..	7½	13¼	18¾	24½	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	5	5	5	4½	----	----	----	----	----	----	----	----	----	----	----	----	----	----
6	Width.....feet..	5½	10¾	15¾	21	----	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	6½	5	5½	5½	----	----	----	----	----	----	----	----	----	----	----	----	----	----
5	Width.....feet..	2¼	8¼	12½	17	21½	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	9	7	5½	5½	5	----	----	----	----	----	----	----	----	----	----	----	----	----
4	Width.....feet..	----	4½	8¾	12¾	16½	20¼	24½	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	9½	8½	8	7½	7½	7	----	----	----	----	----	----	----	----	----	----	----
3	Width.....feet..	----	----	1½	6¾	10½	13¾	16¾	20	23	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	----	14½	11	10½	10	9½	9½	9	----	----	----	----	----	----	----	----	----
2	Width.....feet..	----	----	----	----	----	----	5¼	8½	11½	14¼	16½	19	21¼	----	----	----	----	----
	Depth..inches..	----	----	----	----	----	----	18	16	15	14	14	13	13	----	----	----	----	----
	6 FEET PER SECOND																		
10	Width.....feet..	5½	10¼	15	19¾	24¼	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	6	5	5	5	5	----	----	----	----	----	----	----	----	----	----	----	----	----
9	Width.....feet..	4	9	13	17¾	22	----	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	6½	6	5	5	5	----	----	----	----	----	----	----	----	----	----	----	----	----
8	Width.....feet..	1¾	7¼	11½	15½	19½	23½	----	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	8½	6½	6	6	6	5½	----	----	----	----	----	----	----	----	----	----	----	----
7	Width.....feet..	----	5¼	9½	13	16½	20½	24	----	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	7½	7	6½	6½	6	6	----	----	----	----	----	----	----	----	----	----	----
6	Width.....feet..	----	2	6¾	10¼	13½	17	20½	23¾	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	11	8½	8	7½	7	7	7	----	----	----	----	----	----	----	----	----	----
5	Width.....feet..	----	----	2¼	6¾	10	13	15¾	18¾	21½	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	----	12½	10	9	9	8½	8½	8	----	----	----	----	----	----	----	----	----
4	Width.....feet..	----	----	----	----	4¾	8¼	11	13½	16	18¼	20¾	23¼	----	----	----	----	----	----
	Depth..inches..	----	----	----	----	13	12	11	10½	10½	10	10	10	----	----	----	----	----	----
3	Width.....feet..	----	----	----	----	----	----	----	4¾	8	10¼	12½	15	17	20¾	----	----	----	----
	Depth..inches..	----	----	----	----	----	----	----	17	15	14½	14	13½	13	13	----	----	----	----
2	Width.....feet..	----	----	----	----	----	----	----	----	----	----	----	----	----	6	10¼	14	17	----
	Depth..inches..	----	----	----	----	----	----	----	----	----	----	----	----	----	23	21	20	19	----
	7 FEET PER SECOND																		
10	Width.....feet..	----	3¾	7¾	11	14¼	17¼	20½	23½	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	8	7	6½	6½	6	6	6	----	----	----	----	----	----	----	----	----	----
9	Width.....feet..	----	1¼	6	9½	12¼	15¼	18¼	21½	----	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	11	8	7½	7	7	7	6½	----	----	----	----	----	----	----	----	----	----
8	Width.....feet..	----	----	3¾	7½	10½	13	15¾	18¾	21½	----	----	----	----	----	----	----	----	----
	Depth..inches..	----	----	9½	8½	8	8	7½	7½	7	----	----	----	----	----	----	----	----	----
7	Width.....feet..	----	----	----	4½	8	10½	13	15¾	18¼	21	23	----	----	----	----	----	----	----
	Depth..inches..	----	----	----	10½	9½	9	8½	8½	8	8	8	----	----	----	----	----	----	----
6	Width.....feet..	----	----	----	----	4½	7¼	10	12½	14½	16¾	19	21¼	----	----	----	----	----	----
	Depth..inches..	----	----	----	----	12	11	10½	10	10	9½	9	9	----	----	----	----	----	----
5	Width.....feet..	----	----	----	----	----	----	4½	7¾	10¼	12¼	14¼	16¼	18¼	22	----	----	----	----
	Depth..inches..	----	----	----	----	----	----	14	13	12	11½	11½	11	11	11	----	----	----	----
4	Width.....feet..	----	----	----	----	----	----	----	----	1¾	5¼	7¾	10¼	12	15¾	19	22½	----	----
	Depth..inches..	----	----	----	----	----	----	----	----	20	17	15½	15	14	13½	13	13	----	----
3	Width.....feet..	----	----	----	----	----	----	----	----	----	----	----	----	----	5	9½	12¾	16	18½
	Depth..inches..	----	----	----	----	----	----	----	----	----	----	----	----	----	22	19	18	17½	17

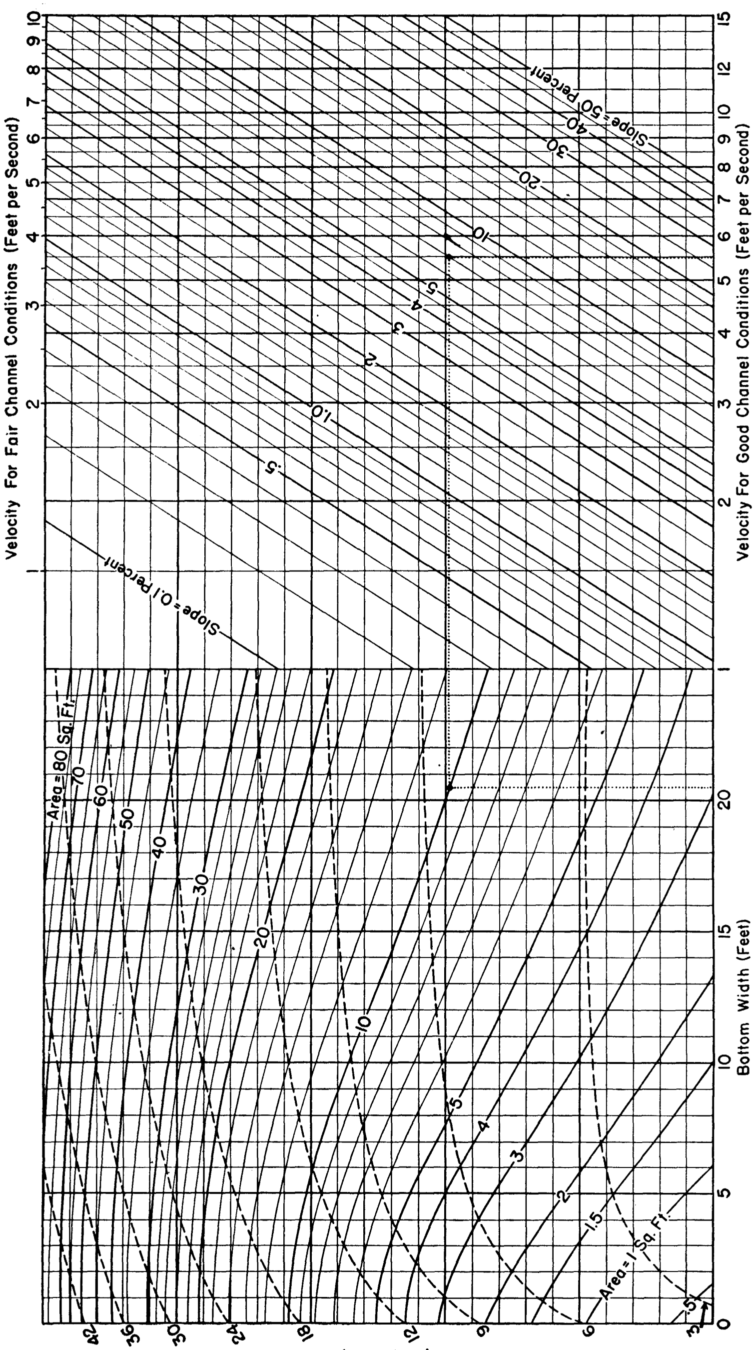

FIGURE 12.—Graphic solution of vegetated channel dimensions (trapezoidal cross section 4:1 side slopes) by the Manning formula. The light dotted line connects the points that represent the velocity, slope, cross-sectional area, and the corresponding depth and bottom width mentioned in the sample problem illustrating the use of the chart.

ditches are sometimes preferred. For flat-bottom channels, width greater than 20 feet are seldom used. If a larger cross section is necessary to care for the run-off, two or more parallel channels are usually preferred to one wide channel.

A much wider range of velocity or other controlling channel conditions that may govern construction dimensions can be covered in a chart than in a table. Futhermore, many outlet channels will be constructed by contractors, surveyors, engineers, or even farmers who may prefer to use a chart rather than a table for determining the dimensions required. For this reason, figure 12 has been prepared. The chart can be used easily when one understands what the different lines and scales represent.

The chart is divided at the center into two distinct parts. On the right-hand side of the chart, the diagonal lines represent channel slopes and the vertical lines represent design velocities. The bottom scale on the vertical lines gives velocities for well-maintained, pliable-grass channels, such as Bermuda or bluegrass. The velocities are higher than those given at corresponding points on the top scale. The top scale is for poorly maintained channels or for coarse covers, such as lespedeza, which have a high frictional resistance to flowing water. On the left-hand side of the chart, the vertical lines represent channel-bottom widths, the dotted curved lines represent channel depths, and the solid curved lines represent channel cross-sectional areas.

To illustrate the use of the chart, suppose a terrace-outlet channel is to be constructed down a 7-percent slope and treated with bluegrass that is to be well maintained and capable of withstanding a maximum velocity of $5\frac{1}{2}$ feet per second. The estimated maximum run-off to be provided for is 55 cubic feet per second. With this discharge and maximum velocity, the channel must have a cross-sectional area of $\frac{55}{5.5}$ or 10 square feet. To find the required channel depth and width, enter the right-hand side of the chart and locate the vertical line representing a channel velocity of $5\frac{1}{2}$ feet per second for good channel conditions. Follow this line upward to the point of intersection with the diagonal line representing a slope of 7 percent. From this intersection pass horizontally to the left-hand side of the chart until the solid curved line representing a cross-sectional area of 10 square feet is intersected. From this point trace a line parallel to the vertical lines until it intersects the width scale and another parallel to the nearest dotted curved line until it intersects the depth scale. The reading on the width scale is about $20\frac{1}{2}$ feet, and the corresponding reading on the depth scale is about 6 inches. In field practice an additional 6 inches of depth is provided for safety, so the constructed depth of the channel is 12 inches.

WEIR-NOTCH CAPACITIES

Structures that may be used in connection with the establishment of proper outlets or disposal systems will generally be of the weir-notch type. The notch, or opening, through which the run-off flows as it passes over the structure, must have adequate capacity to prevent

overtopping and its resulting damage. A common cause of the failure of check dams is insufficient notch capacity. Table 4 gives, for various rates of run-off, the size of the weir notches that will be required for the type of check dams ordinarily used in outlet protection. It is usually desirable to select a notch width that is several times as wide as the depth of the notch in order to avoid undue concentration of the run-off as it passes over the structure. It is also standard practice to construct the notch slightly larger than necessary for computed run-off requirements to provide a factor of safety.

TABLE 4.—*Approximate discharge capacity of rectangular notches in small check dams*[1]

Depth of notch (feet)	Discharge capacity per second when the length of notch is—											
	2 feet	4 feet	6 feet	8 feet	10 feet	12 feet	14 feet	16 feet	18 feet	20 feet	22 feet	24 feet
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
0.5	2.3	4.5	6.8	9.1	11.3	13.6	15.8	18.1	20.4	22.6	24.9	27.2
1.0	6.4	12.8	19.2	25.6	32.0	38.4	44.8	51.2	57.6	64.0	70.4	76.8
1.5	11.8	23.5	35.2	47.0	58.8	70.5	82.3	94.1	105.8	117.6	129.3	141.1
2.0	18.1	36.2	54.3	72.4	90.5	108.6	126.7	144.8	162.9	181.0	199.1	217.2
2.5	25.3	50.6	75.9	101.2	126.5	151.8	177.1	202.4	227.7	253.0	278.3	303.6
3.0	33.3	66.5	99.8	133.0	166.3	199.5	232.8	266.0	299.3	332.5	365.8	399.1
3.5	41.9	83.8	125.7	167.6	209.5	251.4	293.4	335.3	377.2	419.1	461.0	502.9
4.0	51.2	102.4	153.6	204.8	256.0	307.2	358.4	409.6	460.8	512.0	563.2	614.4
4.5	61.1	122.2	183.3	244.4	305.5	366.6	427.7	488.8	549.8	610.9	672.0	733.1
5.0	71.6	143.1	214.7	286.2	357.8	429.3	500.9	572.4	644.0	715.5	787.1	858.6

[1] Computed by formula $Q=3.2\ LH^{3/2}$, where Q=discharge in cubic feet per second, L=length of notch in feet, and H=head of water on crest of notch in feet. For discharges in excess of those shown, the length may be increased proportionately if the same head is maintained. For example, the discharge capacity of a notch 28 feet long and 2.5 feet deep would be twice as large as that of a notch 14 feet long and 2.5 feet deep, or 354.2 cubic feet per second (2×177.1).

CONSTRUCTION OF VEGETATED DRAINAGEWAYS AND OUTLETS

Before complete plans can be made for establishing satisfactory drainageways or outlets on a farm the procedure to be used in preparing the channels and the seedbeds must be decided upon, as well as the method of establishment and the type of vegetation. To determine a practical manner of providing run-off protection during the period in which vegetation is being established is often difficult. The kind or the combination of grasses that will produce necessary protection in a comparatively short period in a given locality should be selected. Recommendations on these points are given in this section. Usually the construction procedure and types of vegetation used will be those most applicable to the locality.

GRADING DRAINAGEWAYS

In the formation of strip outlets, or grassed drainageways, only a minimum amount of excavation or fill work should be undertaken. Frequently the depression selected for run-off disposal will require no work of this kind. If small gullies, hummocks, ridges, sprouts, or shrubs are present, the gullies should be plowed or graded in, the hummocks and ridges leveled off, and the sprouts and shrubs removed.

Trees or shrubs in water channels of any type are usually undesirable because of their tendency to obstruct, divert, or concentrate the flow and cause meandering currents. Only such use of the scraper or drag as may be necessary to develop the depression into its natural cross section or provide a satisfactory seedbed can be justified. Extensive moving of earth or disturbance of soil not only increases the cost of preparation but also usually makes the establishment of the necessary vegetation more difficult.

If the run-off is to be restricted to narrow channels, some excavating and moving of earth is usually required to provide the desired capacity and cross sections. This work can generally be done most effectively with a grader, terracing machine, or scraper. The channels should be shaped up to provide the required cross-sectional area (table 3), and flat side slopes (usually 4:1 or flatter) should be provided so that mowing and the maintenance of channels will be facilitated. Sometimes it may be necessary to level off small washes or ridges in forming the channel. In areas where topsoil is shallow, subsoil unproductive, and grass covers difficult to establish, it has been found desirable to do only the minimum amount of excavating within the channel and to build the sides or channel berms as far as possible by grading the earth up from the outside of the channel. This practice greatly reduces the amount of topsoil removed from the channel and the subsequent work and fertilization required to produce a satisfactory plant cover. If channels are excavated into infertile subsoils it is frequently impossible to establish the desired cover.

The construction of channel berms mainly from the outside may become objectionable if proper end drainage of furrows produced by certain contour row crops is important. It is often desirable to provide furrow drainage for row crops if bedding is practiced, as in potato and cotton culture, or if contour listing is used and furrows of considerable size are produced. Where cultivating produces furrows that have only a small cross-sectional area and where the relief is uneven, row drainage is not so important because the furrows invariably overtop during most rains before the water reaches the end of the rows. The problem is sometimes solved by the use of a vegetated strip along the outside of the outlet channel to facilitate necessary row drainage and provide a turning strip. In other cases, it will be necessary to adjust the amount of channel excavation according to the size of channel required, the depth of soil, the ease of establishing cover, and the necessity for row drainage into the outlet channel.

The berms along outlet channels should have flat enough side slopes to facilitate mowing, and surplus earth excavated from the channel should be spread out, so that it will not form a field barrier. Sometimes it can be conveniently used for making nearby terrace fills. If overfalls in the drainageway or outlet channel are to be protected by means of structures or sod flumes they should be excavated and shaped up to the required structural dimensions. Considerable expense and time can often be saved by doing as much of this excavating as possible with a team and scraper.

ALINEMENT OF TERRACES AND OUTLETS

If individual outlets are used, the ends of the terraces should be shaped and arranged so as to give the minimum concentration of run-off on the outlet slopes. The outlet end of the terrace channel should be wide and flat, so that it will discharge the run-off in a wide, shallow sheet. The vegetation should be extended into the terrace channel so that this wide cross section can be maintained and the development of excess channel grades near the outlet end prevented. If the natural slope of the area onto which the run-off is to be discharged is uniform and parallel to the direction of flow in the terraces, the terraces need extend only far enough into the outlet area to assure the discharge of the run-off onto the vegetated slope. If the natural slope of the area onto which the run-off is to be discharged is at right angles to the terrace flow, it is usually advisable to extend the upper terrace a considerable distance into the grassed slope and systematically reduce the extension of each subsequent terrace down the slope, so that concentration of the discharge from adjacent terraces can be minimized. If the slope of the grassed outlet area is intermediate, that is, neither parallel to the direction of flow in the terrace nor at right angles to it, it may be necessary to make an irregular extension of the terraces to prevent so far as possible excessive concentration of run-off.

Where any type of a collective outlet is used, and particularly where the outlet channel is located in a natural depression, it is often advantageous to turn the ends of the terrace down grade for a short section back from the outlet. By turning the last 50 to 100 feet of a terrace somewhat downhill and providing a corresponding reduction in the depth of channel cut on the upper side, it is possible to bring the bottom of the terrace channel into the outlet channel at or close to ground level without changing the normal terrace grade. In order to do this the last section of the terrace is sometimes constructed with a scraper or fresno, so that more and more of the dirt can be moved from the lower side as the terrace approaches the outlet channel. If it is considered advisable to build the terrace through to the outlet with a grader in the usual manner, the excess terrace grade can be eliminated by placing a small sodded earth fill to the required height across the end of the terrace channel, provided a corresponding increase is made in the height to maintain the necessary channel capacity. The excess excavation in the terrace channel will soon become filled with silt. Turning the ends of terraces downhill makes it easier to get the required channel depth below the outlet elevation of the terrace channel without excessive excavation in the outlet channel. This practice also allows the terraces to have a much straighter approach if the outlet channel is located in a natural depression. Necessary precautions should be taken to prevent excess grades in the terrace channel and maintain adequate capacity.

In order to provide a factor of safety against overtopping, silt accumulation, and insufficient drainage in the terrace channel, grassed outlet channels should be at least 6 inches deeper than the minimum depth required for the discharge capacities. The bottom of the outlet channel should be several inches below the elevation of the terrace

channel at the outlet end, and this overfall should be sloped (at least 4:1) and well sodded to prevent it from advancing up the terrace channel (fig. 13). If the procedure used to establish the sod cover tends to reduce the channel depth, as sodding would, for example, the initial channel depth should be increased sufficiently to compensate for this reduction.

FIGURE 13.—A sodded terrace-outlet channel. Note how the terrace channel is shaped and protected at the discharge end. The broad, flat, sodded section spreads the run-off as it enters the outlet channel and prevents overfalls from advancing up the terrace channel.

If vegetation in the outlet is established before the terraces are constructed, it is generally advisable to terminate terrace construction with the regular terrace equipment far enough back from the outlet so that there will be ample room for turning without damaging the vegetation in the outlet. Each of the terraces can be connected with the outlet channel by constructing this last section with a fresno or scraper. With fresno construction, the team and scraper are worked back and forth over the terrace without injury to the vegetation in the outlet. If a grassed outlet is used as a turning area for heavy construction equipment the vegetation may be damaged to such an extent as to render repair difficult. Fresno construction of the terrace section near the outlet also makes it easier to produce a broad discharge channel to facilitate the maximum spread of the run-off as it leaves the terrace channel. Often it is also necessary to finish terrace construction in this way where terraces terminate at permanent fences or hedgerows.

ESTABLISHING VEGETATION

In many areas it has been found not only hazardous but also expensive to attempt to establish vegetation in drainageways or outlet channels when they are being used for the disposal of run-off. Ordi-

nary seeding procedure, with the necessary fertilization and seedbed preparation, usually provides the cheapest means of establishing grass covers and wherever practical should be followed to reduce the cost of outlets. Newly prepared seedbeds, seeds, fertilizers, and young plants offer little resistance to erosion and are frequently washed out unless special precautions are taken or special practices adopted. Solid or strip sod, if properly anchored, will sometimes carry run-off without harmful results immediately after it has been placed. Sodding is more costly than seeding, however, and the additional expense of sodding may retard the extensive use of vegetative protection. It is sometimes even difficult to anchor newly placed sod in certain channels in such a way that it will not be damaged by heavy run-off. Damage from run-off is more acute in the establishment of vegetation in outlet channels than in wide grassed drainageways because of the higher velocities in the channels. There are several methods that can often be used to save expense and eliminate these hazards in establishing vegetation in outlets.

The first method that should be considered is establishing the outlets before the terraces are constructed. With proper planning, this can often be done, particularly if a complete soil conservation plan for the farm is to be adopted. Complete land use and run-off-disposal plans should be developed at the outset, so that the first outlets or drainageways will be a part of the final plans for the area. When the vegetation is well enough established to withstand additional run-off the terraces can be constructed and connected with the outlet. On some farms several types of outlets will be used, and financial circumstances often will not permit immediate construction of all the necessary terraces and outlets. Under these conditions, areas for which natural outlets are available or for which the outlet channels require solid sodding or mechanical protection can be terraced the first year, while the vegetation is becoming established in other outlets.

Another practice that has facilitated the use of the simpler and cheaper methods of establishing vegetation is diverting the run-off through a temporary bypass until the vegetation in the permanent drainageway becomes established (fig. 14). This procedure can often be used on unterraced as well as terraced areas. On terraced areas this usually requires breaking the terraces or extending them across the permanent outlet channel to a temporary ditch that will carry the run-off without excessive damage until the necessary vegetation is established. Topographical features, the extra work involved, and the extent of the damage that may occur in the temporary channel will largely determine the practicability of this practice.

Subsoiling or other run-off-retention measures may often be used alone or in combination with other practices to facilitate satisfactory establishment of vegetation in drainageways or outlets. Such run-off-retention methods as contour ridging, furrowing, listing, and subsoiling on the contributing watersheds are practical in some places and may sufficiently reduce the run-off on certain soil types to make it possible to establish the necessary vegetation in drainageways. On some of the demonstration projects of the Soil Conservation Service it was found that subsoiling terrace channels and outlets to a depth of about 18 inches reduced the run-off sufficiently during the

following year to permit the establishment of necessary plant covers in the outlets.

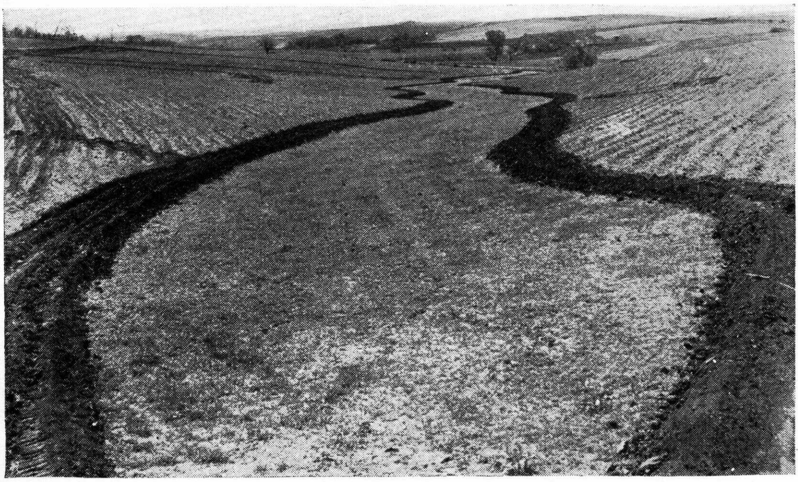

FIGURE 14.—This seeded drainageway is protected from run-off by temporary ditches along the sides of the seeded area. After the vegetation has become established the temporary ditches will be plowed in, and the run-off will then flow down the vegetated drainageway.

Mulching of seeded channels and drainageways has made possible the successful establishment of sod covers by seeding in many areas where seeding otherwise would have been a failure (fig. 15). Properly anchored mulch not only protects the newly prepared seedbed, seeds, and small plants from run-off and hard rains but conserves moisture and produces a surface condition that encourages the germination and growth of small grass seeds. The mulch is produced by spreading a thin but continuous layer of straw, corn fodder, old hay, or brush over the entire seeded area. Two or three tons per acre is usually required. The mulch is anchored by lightweight woven wire or by strands of baling wire on 6- to 12-inch centers. The wire should be staked down every few feet so as to prevent the removal of the mulch by run-off or winds and to hold it in close contact with the ground surface. By the time the grass roots have become established, the mulch is usually rotted sufficiently to make its removal unnecessary, but the wire should be removed before the grass is mowed or grazed. If brush is used, it can be staked down at intervals.

On small areas or at vulnerable points in larger areas, loosely woven burlap tightly drawn and staked to hold it in place has often provided satisfactory protection (fig. 16). This covering retains the moisture and prevents erosion or washing. It may be particularly effective if a turf is to be established on short, steep slopes. Old burlap bags ripped apart or some of the commercial fabrics now on the market may be used. If an open material is used the grass will come up through the meshes; since the covering will soon decay, it need not be removed.

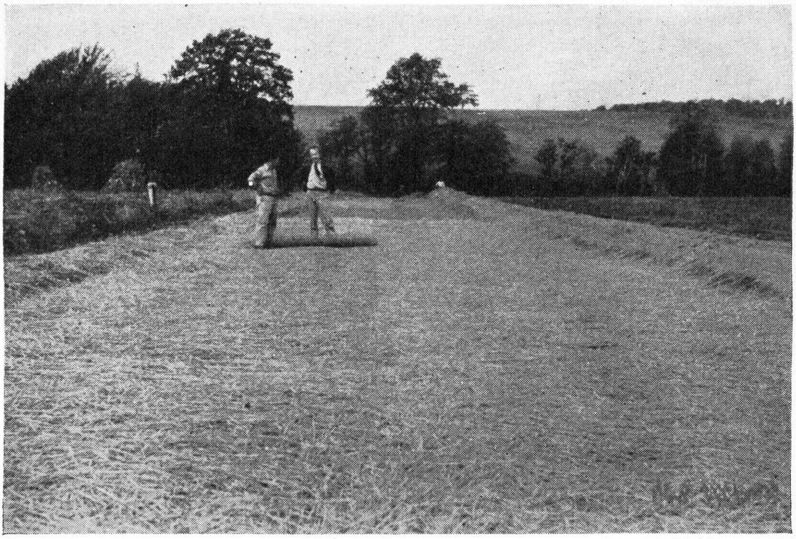

FIGURE 15.—A seeded drainageway protected by a straw mulch held in place by fine-mesh poultry wire. The wire will be removed when the vegetation becomes established.

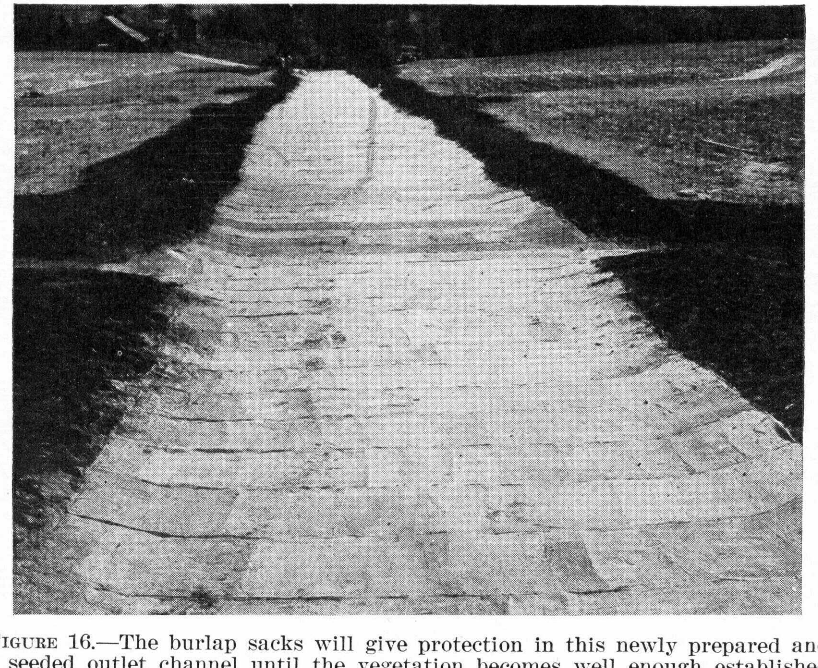

FIGURE 16.—The burlap sacks will give protection in this newly prepared and seeded outlet channel until the vegetation becomes well enough established to carry the run-off safely.

SEEDING

Wherever suitable grass varieties can be readily established from seed the cheapest sod covers can usually be produced by seeding. In some sections where large areas must be vegetated to dispose of run-off, seeding is frequently the only practical method of establishing the necessary protection. This is particularly true in areas where Bermuda grass cannot be used, and even Bermuda, which is most commonly established from stolons, has frequently been established by seed. In other areas seeding is often used in combination with the direct transplanting of sod. Success with seeding is dependent not only on protecting the seed from run-off but also on the use of suitable seed mixtures, good seedbed preparation, ample fertilization, and proper methods of seeding. Since the ultimate success not only of the drainageway but also of any conservation measures on the contributing watershed is dependent on the establishment of a satisfactory cover in the drainageway, heavy applications of seed and fertilizer can usually be justified. Where water is available some artificial watering during periods of drought may even produce profitable results.

It cannot be expected that grasses and legumes can be established readily by seed where the topsoil has been washed away and the fertility of the remaining soil is low. Subsoil as a rule does not respond successfully to the seeding of grasses, even with applications of fertilizer and lime. The fertility must be built up with heavy applications of manure, fertilizer, and lime and by turning under legume crops for green manure. If economically feasible, complete sodding is the surest means of obtaining a satisfactory drainageway under such conditions.

After the drainageway has been properly shaped, a firm seedbed should be prepared by the customary cultural operations (figs. 17 and 18). If a fertilizer is necessary, well-rotted barnyard manure is often the most satisfactory; if a sufficient quantity is available, sometimes as much as 15 to 20 tons per acre should be applied. It can be worked into the soil during the grading and seedbed preparation. Superphosphate at the rate of 400 pounds per acre or its equivalent in basic slag should be used with the manure in humid regions. If manure is not available, a complete commercial fertilizer high in nitrogen, such as 6–8–4 or a 6–12–4, can be used at the rate of 400 to 600 pounds per acre. Commercial fertilizers are generally broadcast and raked into the soil, after which the soil is firmed with a packer. The seed mixture can be broadcast immediately. Sour soils should be limed in accordance with local requirements.

The species of grasses and legumes that should be seeded will vary in different parts of the country. Selection should be based upon the adaptability of the grasses to the locality in which they are to be used, their aggressiveness, and their ability to resist erosion and silting. The use to be made of the seeded area will also govern to some extent the selection of species to be seeded.

Sod-forming grasses are generally preferred to bunch grasses, where both are adapted, because they make a denser turf and a more

FIGURE 17.—This drainageway has been shaped to proper cross section and seeded for run-off disposal. Note the small earth embankments along the sides, used to protect temporarily the seedbed and young plants.

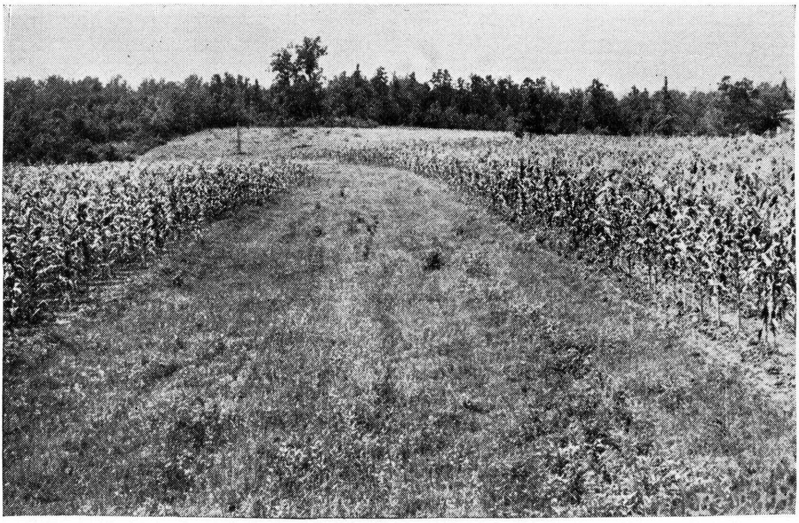

FIGURE 18.—The drainageway shown in figure 17 after the vegetation had been established and the temporary embankment removed.

uniform ground cover. It is generally advisable to seed simple mixtures of adapted grasses and legumes to insure complete stands and early stabilization of the drainageway. As the less well-adapted species thin out, the more aggressive ones will spread to replace them and thus perpetuate a complete ground cover.

In the larger drainageways, where it may be impossible to provide sufficient run-off protection, sowing a quick-growing annual crop to stabilize the drainageway before seeding the grasses is often advis-

able. Small grains, Sudan grass, domestic ryegrass, and similar crops may be seeded in the spring to hold the soil effectively and produce a residue in which to seed the grasses the following fall. Nurse crops may also be seeded with the grasses to afford quick protection, but care must be taken not to seed the nurse crop so thick that it will compete for moisture to the elimination of the grasses or become so thick as to smother the small grass and legume plants. One or two pecks per acre of barley, oats, or other small grain should be sufficient. When the nurse crop becomes tall or too vigorous it should be cut to reduce competition and prevent smothering of the slower growing and more permanent vegetation.

Grass and legume mixtures for pastures are generally seeded 20 to 30 pounds to the acre. Heavier seeding is usually advisable in drainageways, where a thick grass cover is desirable, since some of the seed may be washed away. Thirty-five to forty-five pounds per acre can be used safely in drainageways and outlets that have been properly fertilized, as moisture conditions are generally ideal to support a thick stand. If there is little plant food or moisture, however, heavy application of seed may cause a complete failure.

Since the most desirable species of grasses and mixtures will vary considerably with local soil conditions and climate, it is difficult to give definite recommendations that would apply to all localities. Specific recommendations as to the most suitable grasses should be obtained from the local county agent, State experiment station, or field representative of the Soil Conservation Service.

Early fall seeding usually gives the best results, but some variation in seeding dates is necessary. The southern or less hardy grasses require early spring seeding. In the central and northern Great Plains and western Corn Belt, where grasshoppers are numerous, late-fall seedings are advisable.

Seeding may be accomplished by broadcasting or by drilling. If the seed is broadcast the ground should be firmed by a packer, seeded, and then harrowed lightly to cover the seed. Some plants, as for instance *Lespedeza sericea*, give better stands if the harrowing is omitted. In the semiarid sections drilling is much preferred to broadcasting. Because drilling places the seed in moist soil it gives more rapid and uniform germination and greater assurance of getting a satisfactory stand. To reduce the risk of having the seed washed away, contour tillage of the seedbed and contour drilling are preferred wherever practical. Tillage and drilling operations should at least be conducted in a zigzag pattern that crosses the area as often as is convenient. Even running the drill over the ground two or three times in this manner to plant the desired amount of seed may be advisable to assure more uniform seed distribution and eliminate the effect of rows as much as possible.

SODDING

Where sod is available on nearby areas and local conditions make the establishment of adequate cover by seeding excessively hazardous, it is often necesary to resort to direct transplanting of sod or grass roots. Several methods of transplanting sod have been developed

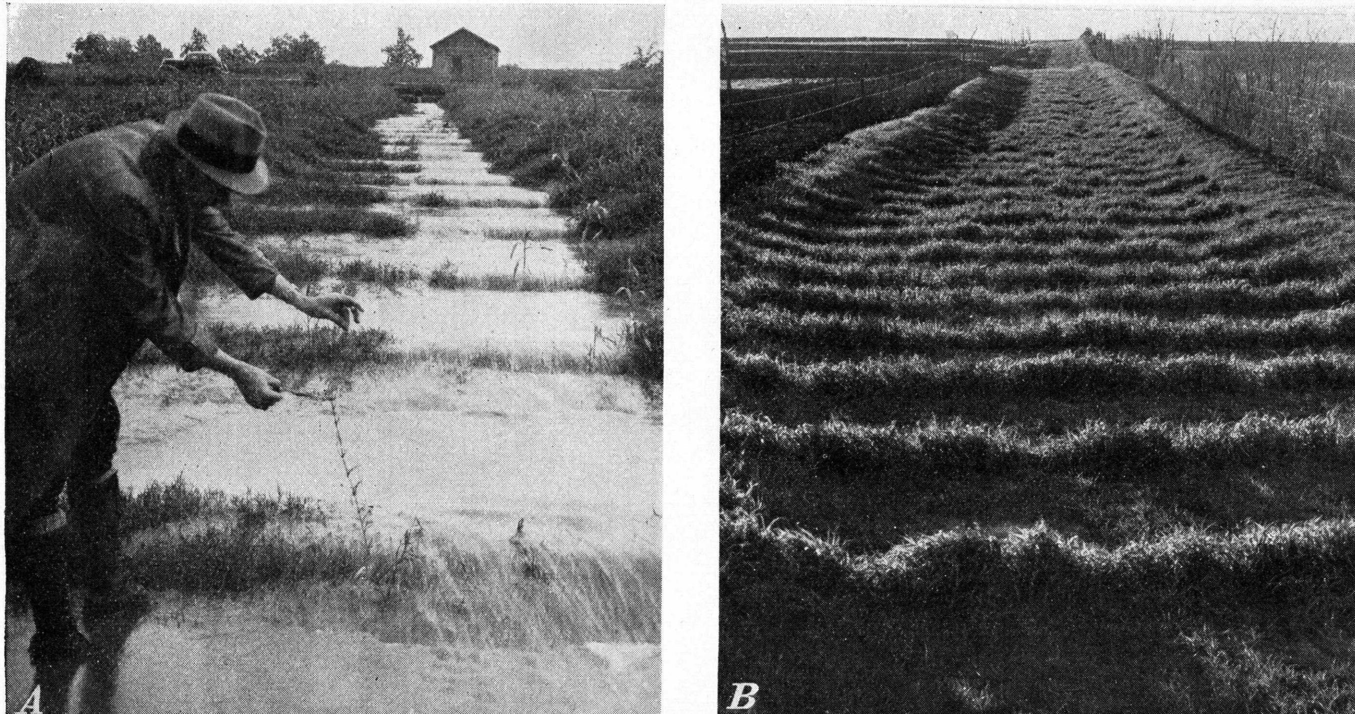

FIGURE 19.—*A*, These Bermuda grass strips protect the channel from erosion. The runners from the grass roots will soon spread over the intervening areas and provide a complete cover. *B*, A series of oat strips at comparatively close intervals provided sufficient protection in this outlet until the grass seeded over the entire channel became established.

that are adaptable to local conditions and various grasses. Strip sodding and solid sodding have been used in practically all areas, and sprigging, spot sodding, and broadcast sodding have been used with good results in many Bermuda grass areas of the Southern States. Strip sodding consists of laying sod in strips approximately on the contour and at regular intervals down the slope. Solid sodding is the transplanting of a continuous layer of sod over an area. Spot sodding is the transplanting of sprigs of grass roots or rootstocks more or less at random. They are usually placed at fairly close intervals. Broadcast sodding is the disking and removing of the topsoil and sod roots from a well-sodded area and the spreading of this mixture as a continuous mulch over the area to be treated.

Establishing plant cover by sodding is most common on areas where temporary run-off protection cannot be provided, where an immediate cover is necessary, or where run-off must be confined to restricted channels. For the best results with any sodding procedure, fertilization, good channel preparation, and careful handling and placing of the sod or roots are necessary. Recommendations for fertilization and sodding dates are similar to those given for seeding.

The use of strip sodding has generally been restricted to the flatter slopes, those of 5 percent or less, and to drainage areas of about 20 acres or less, from which the volume of run-off is not large (fig. 19). Even with these limitations there have been some failures, and some repair has been necessary in other cases because of the tendency for overfalls to develop below sod strips. This tendency has been particularly troublesome in sandy soils. The sod strips are usually cut 12 inches wide and 1 to 2 inches thick. They are placed either in a trench cut to the dimensions of the sod across the bottom of the outlet channel or directly on the channel bottom, and the area between strips is filled with fertile soil and seeded. In either case, the top of the sod strips should be flush with the bottom of the completed channel so the strips will not create unnecessary turbulence and will be less likely to wash out during run-off periods. The spacing of the sod strips has usually ranged from 3 to 6 feet, according to the slope of the channel, a 4-foot spacing commonly being used for average conditions. Whatever spacing is used, it is believed that the vertical interval between strips should seldom exceed the thickness of the sod. The sod strips should be extended up the sides of the channel to at least the maximum run-off depth anticipated.

Field observations have shown that the cost of strip sodding and the labor requirements have been almost as great as for solid sodding. Since strip sodding seldom gives as good results as solid sodding, its use can ordinarily be justified only in areas where there is insufficient sod for solid sodding.

Spot and broadcast sodding are sodding methods used in the establishment of Bermuda grass from rootstalks and stolons. Spot sodding is accomplished by planting rootstock springs in hand-made holes or by dropping them at desired intervals and plowing or disking them in. Disking is the more economical if large areas are to be covered. The root sprigs are usually placed on 12- to 24-inch centers and covered with 2 to 3 inches of soil, which is packed around them. If broadcast sodding is practiced, the area from which the

sod is to be taken is usually disked so as to cut up the Bermuda grass roots and mix them with the topsoil. This mixture is removed by shovels, scrapers, or fresnos and spread in a continuous layer 1½ to 3 inches thick over the area to be sodded. For best results the area should then be disked and packed. This method has the advantage of adding considerable topsoil to infertile areas. The mulch of topsoil and roots offers some resistance to damage by rainfall and run-off although it is not nearly so effective in this respect as solid sodding. Broadcast sodding can be done economically, largely because the gathering and planting of the sod is done almost entirely by equipment. Hand labor is practically eliminated. In some areas a farm manure spreader has been used for spreading the grass roots and soil.

In bluegrass areas, where the less-expensive seeding procedure has been impractical, solid sodding has been more satisfactory. Even in Bermuda grass sections solid sodding has frequently been necessary where an immediate channel cover is required or where slopes are steep (fig. 20). The sod is cut from a well-grassed area and laid in continuous strips across the water channel and thoroughly tamped into place. It is usually cut in strips 1 foot wide and 1 to 2 inches thick. Transporting the sod strips on 6- to 10-foot boards, rather than attempting to roll them, has facilitated the moving of the sod. If newly laid sod is exposed to heavy run-off before the grass roots have had a chance to anchor the sod strips, it is frequently necessary to stake or staple the sod down at regular intervals. Anchorage by lightweight woven wire and stakes has been necessary in some places. The use of commercial or home-made sod cutters will materially assist in reducing the cost of sodding (figs. 21 and 22).

In some areas considerable expense has been saved by a combination of sodding and seeding procedures in establishing vegetation in drainageways. Strip or spot sodding with seeding of the intervening areas has been used in some sections. In others a low portion of the channel provided to carry the greatest amount of run-off is sodded and the remainder seeded. In wide V- or concave-shaped channels a strip several feet wide in the center of the channel is sodded solid, and the remainder of the cover is established by seeding. Occasional sod cut-off strips are extended up the sides of the drainageway to divert all low-flow run-off to the sodded portion. If terraces have been constructed, sodded strips should be provided to convey the run-off safely from each terrace channel to the sodded portion of the outlet channel.

CONSTRUCTION OF MECHANICALLY PROTECTED OUTLETS

Where it is necessary to provide mechanical protection in terrace outlets, low, permanent structures of the weir-notch type are usually used. They may be built of brick or stone masonry, reinforced concrete, precast concrete blocks, or a combination of these materials. Usually the materials available locally will be used. In areas where good-quality rock is available and where the labor necessary in quarrying and hauling is not excessive, rubble-masonry construction will usually be preferred. In order to provide a more stable structure

FIGURE 20.—*A*, Sod is being transplanted over this outlet channel in order to get a protective covering immediately; *B*, the sod has been cut and rolled preparatory to transportation to an area that is to be sodded.

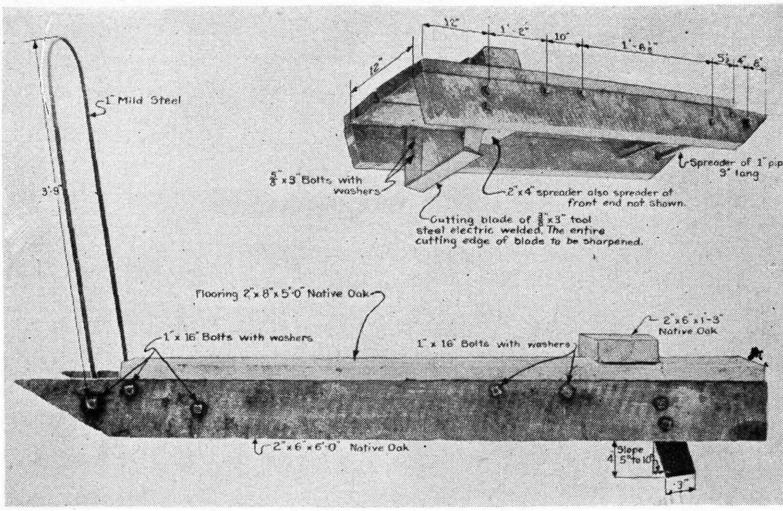

FIGURE 21.—A home-made sled-type sod cutter. For satisfactory operation special care must be taken in the construction and adjustment of the cutting blade.

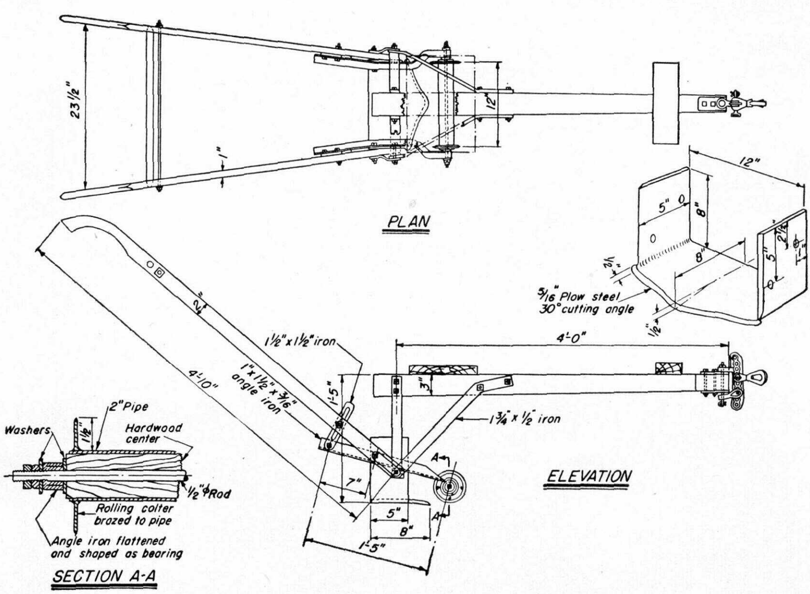

FIGURE 22.—A home-made walking-plow type of sod cutter. Properly constructed cutters of this type have given particularly good results in harvesting bluegrass sod.

and eliminate the danger of cracking, reinforced concrete is often preferable for the apron slab and cut-off walls regardless of the kind of material used in the rest of the structure. The apron slab should have a minimum thickness of 5 inches for dams up to 2 feet high. In dams more than 2 feet high this minimum thickness should be increased about 1 inch for each 2 feet or fraction of a foot of additional height. As far as possible, each structure should be built as a unit so that in the event of partial failure arising from a wash-out around the end the structure itself will not fail and can be repaired by the replacement of earth around the washed-out parts.

Some general specifications for the construction of small masonry check dams and their location with respect to channel and terraces are shown in figure 23. The specifications apply only to the smaller type of structures. If structures higher than 4 to 5 feet are required, it is advisable to have separate plans and specifications prepared by a competent engineer. In ordinary work these higher structures are usually not required. Satisfactory structural protection can often be provided for a high overfall by the use of two or more low structures. In order to reduce the possibility of the structure failing because of wash-outs, care should be taken to provide ample notch capacity for the contributing drainage area (table 3), impervious foundations, and hindrances to seepage around the structure. Cut-off walls should extend well into the bottom and sides of the channel excavation, and an impervious type of soil should be firmly tamped around the structure. Particular care should be taken to see that head-wall extensions go far enough into the soil to provide adequate protection even after the side of the ditches slough off to a natural angle of repose. On colloidal soils, such as the Texas blackland, which tend to crack and shrink away from structure walls during dry periods, further precautions must be taken in order to minimize wash-outs. In soils of this type it has been found advantageous to mix a good portion of sand or manure (usually sand) with the earth that is used to backfill around the structure and then protect the surface with a good sod cover. All earth fills, backfills, or slopes subject to washing should be protected with vegetation.

Outlets that are to be protected by structures should be excavated to accommodate the structures and the amount of run-off to be handled. Although it is not always necessary to excavate outlet channels fully where structural protection is to be provided it is usually desirable to do so wherever convenient so the sides can be sloped, berms leveled off, and some vegetation established thereon. In some channel outlets only a minimum amount of excavation is required to open up the channel, and the remainder of the earth is washed out of the channel by subsequent run-off. Plowing between rains is very helpful in hastening this process. Structure locations must be excavated at least to the outside dimensions of the structures, and if the masonry cannot be poured directly against the earth, additional excavation is usually required in order to provide adequate working space around the structure. Most of the channel can be excavated with graders or scrapers, and "step cutting" of the channel with scrapers at the location of the structure will often reduce much of the hand labor required for the excavation. Step cutting is the

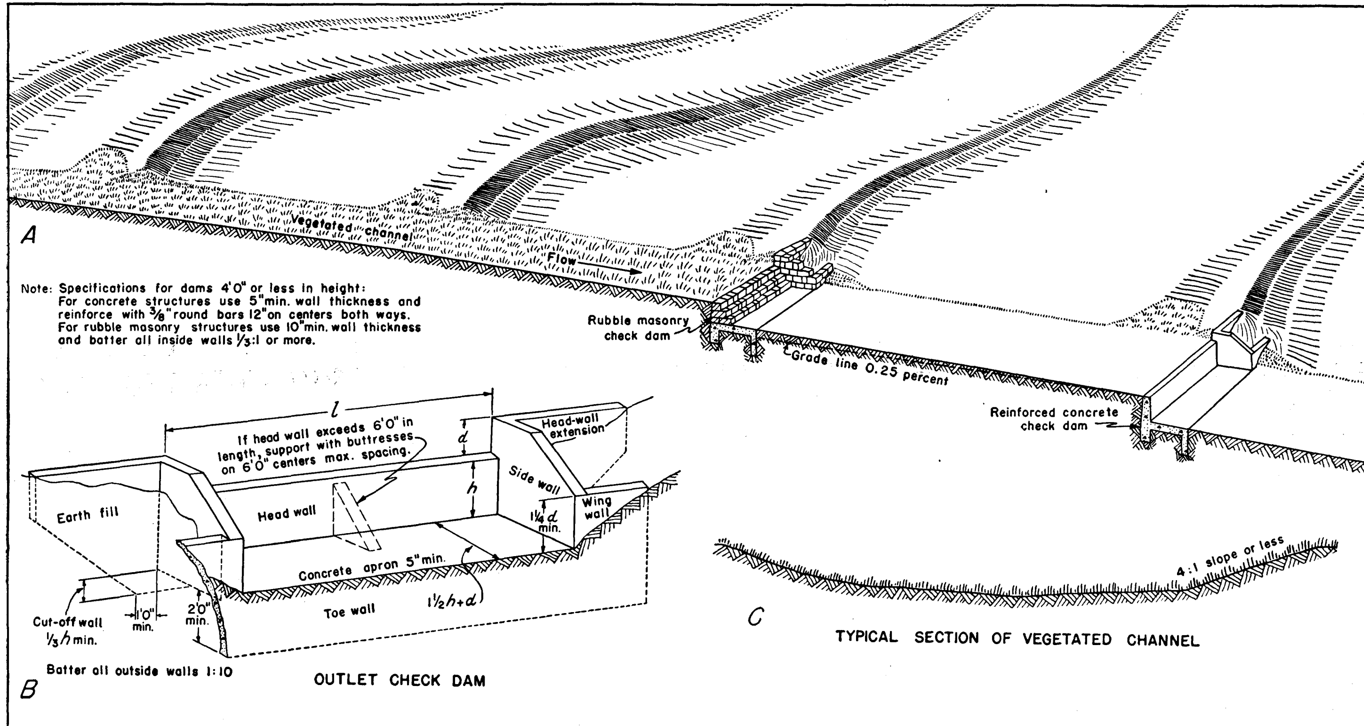

FIGURE 23.—A terrace-outlet channel that is protected from erosion by a combination of vegetation and mechanical structures: *A*, A sectional view, which shows vegetative protection in the upper reaches of the channel and check dams in the lower part; *B*, construction details of the check dams; *C*, cross section of the grassed channel.

excavation of a drop across the channel at the location of the structure.

The weir notch of terrace-outlet structures should seldom be less than 18 inches deep, and the elevation of the weir crest should be at least 1 to 2 inches below the channel elevation at the terrace outlet. This drop provides some allowance for rough construction practices and avoids the possibility of restricted terrace drainage as a result of the crest's being finished higher than the bottom of the terrace channel. If the volume of run-off over the terrace-outlet structure is large it may be desirable to deepen the notch in order to avoid excessive widths, but extreme care must be exercised to protect the drop from the elevation of the terrace channel to that of the weir crest and prevent overfalls from advancing up the terrace channel. This drop should be sloped and sodded.

A grade of 0.25 percent from the weir crest of the lower dam to the bottom of the apron slab of the dam immediately above will usually provide stable channels between structures. Since the top of the apron slab should never be constructed to a higher elevation than the bottom of the channel, the actual grade in the channel will be from the top of the apron slab to the weir crest of the lower structure. Determining channel gradients in this manner has the effect of increasing the actual grade considerably if structures are close together and reducing it if they are more widely separated. Since the channel velocity is largely dissipated at each structure and close spacing of structures does not permit the velocity to accelerate for any great length of time, it is believed that the slightly steeper grade for short distances will usually be safe. In some localities where soils are very erodible a level gradient from the top of the apron on one dam to the weir notch on the dam immediately below is necessary. Care must also be exercised to assure a stabilized grade below the last structure in an outlet channel. Too steep a gradient below structures leads to the development of overfalls, which ultimately undermine or endanger the structure.

The alinement of outlet structures with respect to the terraces should not be overlooked in planning a terrace system in which mechanically protected outlets are to be used. The outlet structures should be located and connected with the terrace so that the head-wall extension projects into the terrace ridge. If a central outlet channel is used, into which terraces enter from both sides, the terraces on opposite sides should approach the channel directly opposite each other, so that the one outlet structure will serve both terraces. This practice gives a systematic appearance with any type of collective outlet. It is not essential, however, in vegetated channels. In order to reduce the amount of excavation for the structure or to permit a straighter approach of the terrace to the outlet it is often advisable to locate the structure downhill as much as 1 foot in vertical elevation from the ordinary location. The last section of the terrace is also moved downhill in a manner similar to that described under Alinement of Terraces and Outlets (p. 26). Even though the terrace and outlet structure are moved downhill, same weir-crest elevation and terrace-channel grade are maintained.

It is usually advisable to use only one outlet structure for each terrace interval. On the steeper slopes it may sometimes be neces-

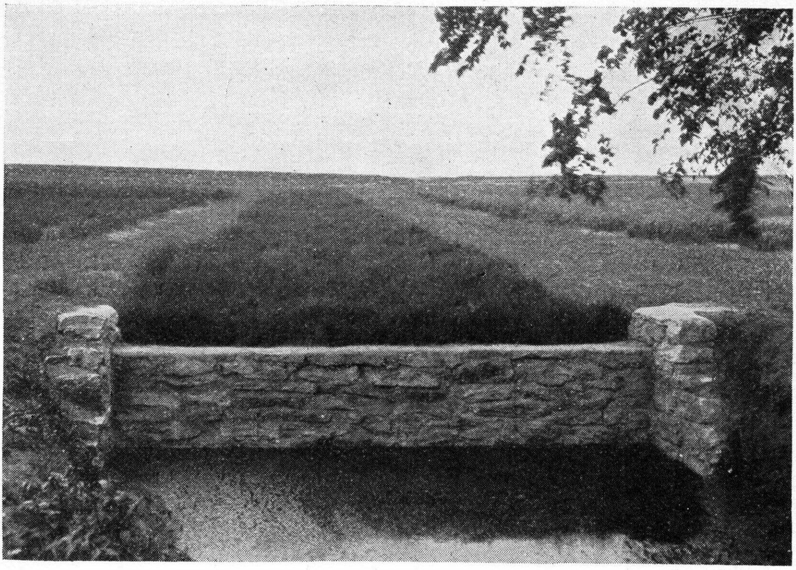

FIGURE 24.—A masonry structure has been used at the lower end of the channel to carry the run-off over a critical overfall to a stabilized drainageway.

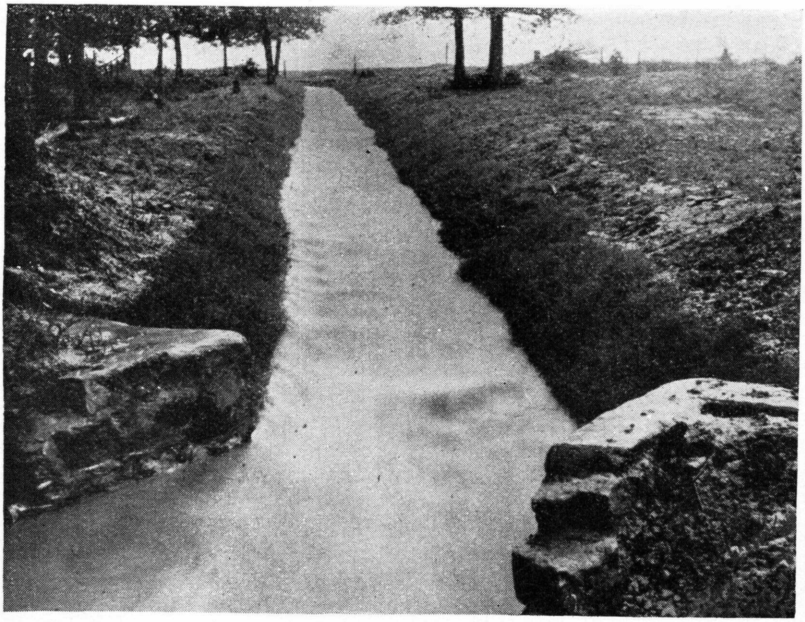

FIGURE 25.—This is the type of structure most commonly used if structural protection is necessary in farm drainageways.

sary to use two structures for each terrace interval, in which case the second structure is usually located midway between the terraces. Structures at bends in structurally protected channels should be located so that they will discharge the run-off parallel to the direction of the channel below the structure. With this procedure some riprapping or protection of the channel side by sodding may be necessary immediately above the structures, but the turbulence and danger of undercutting below the structures will usually be reduced to a minimum. Figures 24 and 25 show masonry structures at critical points in an outlet channel.

If run-off water must be conveyed over steep slopes it may sometimes be necessary to resort to high-velocity channels or continuous flumes (fig. 7). Structures of this type will usually have a very limited use, and capacity computations and design specifications should be made by a competent engineer. The steep slopes produce such high channel velocities that a comparatively small cross-sectional area usually permits a high rate of run-off disposal. Besides providing ample cut-off walls to prevent excessive seepage between the earth and channel lining, an apron or stilling basin must be provided at the end of the flume to dissipate the run-off velocity safely. A long, spreading type of apron may be used, or sufficient outlet protection can sometimes be provided by continuing the flume several feet below the water elevation in an adjacent stream.

MAINTENANCE

The development of satisfactory drainageways and outlets usually requires considerable attention, patience, and ingenuity. The methods and materials used, the soil and rainfall conditions, and the season of the year at which the work is done all have a marked influence on the success attained. Discouraging results are frequently experienced when high-intensity rains or periods of severe drought follow the installation of the initial structures or the planting operations. An attempt may even result in complete failure the first time, but produce satisfactory results when repeated. If necessary precautions are taken and the work conducted in a systematic and thorough manner, the results will usually be satisfactory. After an adequate water-disposal system has been established for a farm it cannot be considered permanent and thereafter neglected (fig. 26). Systematic inspection, repair, and maintenance must be carried out year after year in order to assure proper run-off disposal and adequate protection of the drainageways.

New drainageways and outlets should be inspected periodically. Especially after heavy rains they should be examined to determine whether they are functioning properly or need minor repairs. This is particularly true in drainageways and outlets in which the grasses are not fully established. Some minor adjustment or repair during this period may often prevent failure in establishing the cover. Damaged sod or washed-out seed should be replaced immediately, and any other condition that appears unsatisfactory or undesirable should be corrected. Mechanical structures are also more subject to failure when first installed because it usually takes a year or so for them to

become thoroughly settled, compacted, or sealed. Wash-outs are usually small at first and are easily repaired. If neglected, they enlarge until repair frequently becomes impractical and the entire structure must be replaced.

Silting of grassed drainageways frequently becomes serious. If the run-off carries silt from the adjacent fields, this soil is usually

FIGURE 26.—Overgrazing, rodents, mechanical damage, or inadequate maintenance may start overfalls of this type. Unless checked, this overfall will gradually advance and enlarge until the entire drainageway is destroyed.

filtered out by the vegetation and deposited in the drainageway (fig. 27). This deposit is not only detrimental to certain varieties of grasses, but it also reduces the capacity of the drainageway. When sufficient silt has accumulated to make the capacity inadequate, overtopping leads to the formation of gullies along the sides of the drainageway. The way to combat overtopping and gullying is to prevent silt being washed from the fields. This can be done most effectively by applying adequate soil conservation measures on the drainage

FIGURE 27.—Silt from improperly protected fields fills this drainageway.

area. As an additional factor of safety, drainageways should be made wide enough so that a little silting will not cause overtopping.

Silting and the danger of overtopping can also be minimized by properly maintaining the vegetation in the waterway. It should be mowed at regular periods to prevent the formation of a rank growth. A tall growth of vegetation reduces the discharge capacity and velocity unnecessarily and retains more silt than a shorter growth. Even though the drainageway is grazed, some mowing will usually be necessary to control the growth of tall weeds and sprouts. Proper mowing and grazing of the vegetation will also tend to develop a cover and root system that is more resistant to erosive run-off velocities. If a restricted-channel type of outlet is used, silting can also be minimized by designing for nonsilting velocities wherever practical. Silted drainageways or channels must be cleaned out or enlarged so that the required run-off capacity may be renewed.

All structures and plantings in drainageways and outlets must be protected from damage by livestock and rodents. While some grazing is usually beneficial, overgrazing and excessive trampling by livestock destroys the plant cover and causes failures. It is particularly important that grazing be prohibited when the ground is soft and that some type of obstruction be used wherever necessary to prevent livestock from forming paths up and down drainageways. Hogs are particularly destructive because they root up vegetation and damage structures. Burrowing rodents frequently cause failure of drainageways by destroying the sod and digging through or around structures. Poisoning or trapping the rodents may be necessary for adequate protection.

In some areas it is customary to use drainageways as roadways, but this practice should not be followed since it usually destroys the vegetation and starts run-off concentration or gullying.

All types of drainageways and outlets require inspection, maintenance, and timely repair if a long period of satisfactory service is to be expected. If neglected, they soon become ineffective, and the effort and money expended in their establishment are wasted.

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